

A STUDY OF CONSTRUCTION AND DEMOLITION WASTE LEACHATE FROM  
LABORATORY LANDFILL SIMULATORS

By

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## LIST OF ACRONYMS AND UNITS OF MEASURE

|       |  |
|-------|--|
| BDL   | Below Detection Limit                      |
| C&D   | Construction and Demolition                |
| CCA   | Chromated Copper Arsenate                  |
| COD   | Chemical Oxygen Demand                     |
| DAF   | Dilution Attenuation Factor                |
| DO    | Dissolved Oxygen                           |
| FLAA  | Flame Atomic Absorption                    |
| GFAA  | Graphite Furnace Atomic Absorption         |
| IC    | Ion Chromatograph                          |
| mg/L  | Milligrams per Liter                       |
| mS/cm | Millisiemens/centimeter                    |
| MSW   | Municipal Solid Waste                      |
| NPOC  | Non-Purgeable Organic Carbon               |
| SPLP  | Synthetic Precipitation Leaching Procedure |
| TDS   | Total Dissolved Solids                     |
| TCLP  | Toxicity Characteristic Leaching Procedure |
| µg/L  | Micrograms per Liter                       |



Abstract of Dissertation Presented to the Graduate School  
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Construction and demolition (C&D) waste represents one of the larger components of solid waste from municipal activities in the United States. The waste is often disposed of in unlined C&D waste landfills. It has historically been assumed that leachate produced from C&D waste landfills is innocuous relative to that of municipal solid waste landfills and hazardous waste landfills. Consequently, very little attention has been focused on leachate produced from C&D waste landfills and its characteristics.

In recent years, the potential for adverse environmental impacts posed from C&D waste disposal has been acknowledged, and some impacts have been documented. Consequently, recent federal regulations have increased operating and monitoring for requirements at C&D waste landfills. However, the degree of control needed and the environmental impacts posed still remain a subject of debate. More information is needed to determine the true nature of C&D waste leachate and its potential impacts on the environment.

Research was performed to simulate and characterize C&D waste leachate in the laboratory. Leachate samples were collected and analyzed for a number of chemical parameters including conventional water quality parameters and heavy metals. Experiments were conducted to examine the impact of different components in the C&D waste stream, the depth of landfilled waste, changes in leachate constituents over time, and to identify problematic leachate constituents.

Leachate resulting from laboratory lysimeters (landfill-simulators) containing mixed C&D waste generated a strong hydrogen sulfide odor. Sulfate reducing bacteria under anaerobic conditions utilized dissolved sulfate from gypsum drywall to produce hydrogen sulfide. A few potentially problematic contaminants in C&D waste leachate, which exceeded the drinking water standards, were identified: sulfate, total dissolved solids, arsenic, chromium, iron, and manganese.

Sulfate resulting from dissolution of gypsum drywall was one of the predominant ions observed in the leachate during solids and ion balance analyses. High concentrations of sulfate, calcium and alkalinity were responsible for most of total dissolved solids concentrations in the leachate (> 90%). The most likely source of arsenic and chromium was chromated copper arsenate (CCA)-treated wood. Arsenic is of particular concern due to the anticipated lowering of the drinking water limit as well as a growing prevalence of CCA-treated wood waste in the C&D waste stream. The contaminant in the leachate that exceeded the drinking water standard by the greatest magnitude was manganese, a result of wood. Copper, iron, and zinc were apparently reduced in concentration in the leachate via precipitation as insoluble metal sulfides.

The concentration ranges of pollutants in leachate from the laboratory investigations were within the range of data reported in the literature for actual C&D waste landfills, suggesting that controlled laboratory scale experiments can provide valuable information regarding leachate quality and formation processes within C&D waste landfills. The information gathered suggests that while leachate from C&D waste landfills should be less harmful to the environment than other types of landfills, unlined C&D waste landfills may impart deleterious characteristics to groundwater in some hydrogeologic settings.

## CHAPTER 1 INTRODUCTION

### 1.1 Problem Statement

Construction and Demolition (C&D) waste represents one of the larger contributions of solid waste from municipal activities in the United States. C&D waste is generated from construction, renovation, and demolition of buildings and other such structures. Residential, commercial, industrial, and governmental sectors all contribute to the C&D waste stream. The U.S. Environmental Protection Agency (US EPA) estimated that 124 million metric tons of building-related C&D waste, or 1.2 kg per person per day, were generated in the U.S. in 1996 (US EPA, 1998a).

While the composition of C&D waste varies as a function of the activity generating the waste, as a whole, the major components of C&D waste include wood, concrete, metal, roofing material, cardboard and gypsum wallboard. Minor amounts of other components such as electrical wire, insulation and carpet can also be found in the C&D waste stream, including small amounts of hazardous chemicals (e.g., solvent containers, lead-based paint, mercury vapor lamps). A large amount of C&D waste generated in the United States is disposed of in unlined landfills. The remaining waste is either recycled, or disposed of in municipal solid waste (MSW) landfills or in other non-permitted disposal sites (US EPA, 1998a).

As moisture resulting from precipitation or groundwater intrusion interacts with landfilled C&D waste, leachate is produced. The leachate chemical composition is

dictated by a number of processes (physical, chemical, and biological) occurring within the landfill. Although numerous researchers have studied the characteristics of leachate from municipal solid waste landfill (Lu et al., 1984; McGinley and Kmet, 1984; Wigh, 1984; Emberton, 1986; Lema et al., 1988; Farquhar, 1989; Reitzel et al., 1992; Robinson and Gronow, 1993; Al-Muzaini et al., 1995; Lo, 1996; Fatta et al., 1999; Urbini et al., 1999), very little attention has been given to leachate produced from C&D waste landfills. This results from the prevailing belief that land-disposed C&D waste is innocuous relative to the disposal of municipal solid waste and hazardous waste. This assumption stems from the idea that C&D waste landfills do not accept large quantities of hazardous waste and that the accepted waste is relatively stable and inert. Consequently, leachate from C&D landfills would appear to pose minimal threat to the environment. Thus, most states do not require the same level of environmental protection (e.g., landfill liners, leachate collection systems, etc) for C&D waste disposal facilities as landfills permitted to receive municipal solid waste. As a result, little is known about quality and quantity of leachate generated from C&D waste landfills.

In recent years, it has been realized that detrimental environmental impacts from C&D waste disposal are possible, and some impacts have been documented (Norstrom et al., 1991; US EPA, 1995a, 1995b). Recent federal and some state regulations have increased the requirements for operators at C&D waste landfills (Federal Register, 1996; FAC, 1997). Such measures include location restrictions, operation and training requirements, groundwater monitoring, and financial assurance. In some areas of the United States, state and local regulations go beyond federal rules and require the disposal of C&D waste in lined landfills.

The degree of control needed and the environmental impact posed by land-disposed C&D waste remain a subject of debate. This results mostly from the very limited amount of data available regarding the characteristics of leachate produced at C&D landfills and its impact on groundwater. One difficulty in collecting information on C&D waste landfill leachate is the lack of lined landfills that accept only C&D waste. In situations where a liner is required, C&D waste is often co-disposed with other wastes. Nevertheless, several investigators have collected and summarized available information on C&D waste leachate (Interpoll, 1992; WMI, 1993; NADC, 1994; US EPA, 1995a; US EPA, 1995b). Previous research includes a few specific studies from field sites that relate to C&D waste leachate and a number of surveys of existing regulatory and compliance information from C&D waste landfills in the United States.

These previous studies provided the ranges of chemical constituents in C&D leachate and potentially problematic contaminants. However, a number of unknowns are still associated with the true nature of C&D waste leachate and its impacts on the environment. For example, some of the unknowns are changes in leachate quality with respect to time, how different components impact leachate chemical composition, and how metals behave. C&D waste landfill leachate has not been characterized to the extent that MSW landfills have. Additional knowledge of what leaches from C&D waste landfills would help determine under what circumstances liners are needed, if at all. It would also allow more appropriate siting, construction, and permitting of new C&D waste disposal facilities. More information on the characteristics of C&D leachate would help assess which C&D waste components require additional care and monitoring as well as which components can be safely mono-filled with minimal control.

## 1.2 Scope of Research

The research presented in this dissertation was conducted to address many unknowns associated with C&D waste leachate. A laboratory study was conducted to simulate C&D waste leachate in laboratory C&D waste leaching columns (or lysimeters). Leachate samples were collected from laboratory lysimeters containing mixed C&D waste and analyzed for a number of parameters. Leachate characteristics of individual C&D waste components (e.g. concrete, wood) were investigated using both single-component lysimeters and batch leaching tests. The results are presented and discussed in a manner similar to previous studies that characterized leachate resulting from landfilled municipal solid waste (MSW) (Qasim and Burchinal, 1970; Chian and Dewalle, 1977; Johansen and Carlson, 1976; Raveh and Avnimelech, 1979; Walsh and Kinman, 1981; Wigh and Brunner, 1981; Wigh, 1984; Chen, 1996; Andreas et al., 1999; Öman et al., 1999).

## 1.3 Objectives

The objectives of this study were as follows:

- 1) Determine leachate characteristics from laboratory landfill simulators containing a typical composition of mixed C&D waste
- 2) Determine sources of contaminants in C&D leachate based on leachate quality data from individual C&D waste components (batch tests and lysimeter experiments)
- 3) Evaluate the impact of waste depth on contaminant leaching and its strength by leachate quality data from the laboratory lysimeters (single vs. serial)

- 4) Compare the results of the C&D waste leachate simulated in the laboratory to actual C&D landfill leachates
- 5) Assess possible environmental impacts.

#### 1.4 Organization of Dissertation

This dissertation is organized into a series of six chapters followed by four appendices. Chapter 2 presents an extensive review of the literature with regard to C&D waste, leachate formation resulting from waste decomposition, and previous C&D waste leachate studies. Chapter 3 presents the methodology used in the laboratory simulation of C&D waste leachate. The results of the laboratory C&D leachate tests are presented in Chapter 4. Chapter 5 discusses the results from this study with respect to the objectives presented in the previous section. A final chapter provides conclusions and recommendations for further research. The appendices include raw data and quality control and quality assurance data from both laboratory lysimeter experiments and batch experiments.



## CHAPTER 2

### LITERATURE REVIEW

One of the larger fractions of the solid waste stream resulting from municipal activities is construction and demolition (C&D) waste. Much of the C&D waste disposal methods used in the United States rely on land disposal (i.e. landfilling) without having a bottom liner system. In recent years, chemical characteristics of C&D waste leachate have become the subject of increasing concern with respect to possible groundwater contamination (Hamel, 1989; Norstrom et al., 1991; US EPA, 1995a, 1995b). Yet there is little information available in the literature on the subject. Knowledge of the chemical composition of leachate is necessary when evaluating potential leachate pollution impacts, and determining appropriate leachate management and regulatory requirements for C&D waste landfills.

The following sections provide background information on C&D waste, an overview of the mechanisms of leachate formation in landfills, and a summary of previous C&D waste leachate studies.

#### 2.1 Background of C&D Waste

##### 2.1.1 Definition of C&D Waste

Construction and demolition waste results from the construction, renovation and demolition of buildings, roadways, bridges, and other manmade structures. The types of

materials found in C&D waste include not only the elements used as primary building materials, but also various paints, sealants, adhesives and fasteners used in construction. Construction and demolition waste also includes packaging material and land clearing debris.

While C&D debris is not specifically defined in a federal statute or regulation, in a recent report, the US environmental protection agency (EPA) defined C&D debris as (US EPA, 1998a):

Waste material that is produced in the process of construction, renovation, or demolition of structures. Structures include buildings of all types (both residential and nonresidential) as well as roads and bridges. Components of C&D debris typically included concrete, asphalt, wood, metals, gypsum wallboard, and roofing. Land clearing debris, such as stumps, rock, and dirt, is also included in some state definitions of C&D debris.

States have developed their own definitions of C&D waste (WMI, 1993). In Florida, for example, C&D debris is defined in the regulations as follows (FAC, 1997):

Construction and demolition debris" means discarded materials generally considered to be not water soluble and non-hazardous in nature, including but not limited to steel, glass, brick, concrete, asphalt material, pipe, gypsum wallboard, and lumber, from the construction or destruction of a structure as part of a construction or demolition project or from the renovation of a structure, including such debris from construction of structures at a site remote from the construction or demolition project site. The term includes rocks, soils, tree remains, trees, and other vegetative matter which normally results from land clearing or land development operations for a construction project; clean cardboard, paper, plastic, wood, and metal scraps from a construction project; effective January 1, 1997, except as provided in Section 403.707 (13), F.S., unpainted, non-treated wood scraps from facilities manufacturing materials used for construction of structures or their components and unpainted, non-treated wood pallets provided the wood scraps and pallets are separated from other solid waste where generated and the generator of such wood scraps or pallets implements reasonable practices of the generating industry to minimize the commingling of wood scraps or pallets with other solid waste; and de minimis amounts of other nonhazardous wastes that are generated at construction or demolition projects, provided such amounts are consistent with best management practices of the construction and demolition industries.

### 2.1.2 Sources of C&D Waste

Sources of C&D waste include construction and demolition activities, renovation activities, natural disaster, and site clearance. It is helpful to classify C&D waste by the source of origin to understand what type of C&D waste can be generated. Table 2-1 presents the sources of C&D waste and their components. The components of C&D waste differ as a function of the type and size of the structure and the exact nature of the construction and demolition activity. For example, waste from a demolished building is primarily a mixture of brick, concrete and other substances, whereas waste from road construction contains mainly asphalt pavement and soil.

**Table 2-1 Components of C&D Waste by Sources of Origin**

| <b>Source</b>           | <b>Components</b>  |
|-------------------------|--|
| Building construction   | Brick, wood, concrete, wallboard, cardboard, and roofing materials.                                  |
| Building demolition     | Mixed rubble, concrete, steel, brick, timber, roofing shingles, and waste from fixtures and fittings |
| Renovation              | Wood, fittings, carpet waste, carpet pad, electrical fixtures, wallpaper, and cardboard              |
| Roadwork and Excavation | Concrete, asphalt, sand, stone, and earth fill   |
| Site clearance          | Trees, brush, earth, dirt, concrete, and rubble  |

Source: Brickner, 1992

### 2.1.3 Components of C&D waste

The primary components of C&D waste include wood, concrete, metal, asphalt (pavement and roofing), gypsum drywall, dirt, vegetation, cardboard, and plastic. Minor amounts of other components can be found in the C&D waste stream, including small amounts of hazardous chemicals. Table 2-2 presents a list of various C&D waste components and some examples in each component category.

**Table 2-2 Components of C&D waste**

| <b>Categories</b>  | <b>Examples</b>                            |
|--------------------|--|
| Asphalt            | paving, shingles                           |
| Earth              | sand, dirt                                 |
| Electrical         | fixtures, wiring                           |
| Insulation         | asbestos, fiberglass                       |
| Masonry and Rubble | bricks, tile                               |
| Metal              | aluminum pipe (steel, copper)              |
| Paint              | paint containers and waste, paint products |
| Paper Products     | cardboard, fiberboard                      |
| Petroleum Products | brake fluid, waste oils and greases        |
| Plastics           | pipe (PVC), Styrofoam                      |
| Roof Materials     | roofing shingles, roofing tar              |
| Vinyl              | flooring, doors                            |
| Wall Coverings     | drywall (gypsum), plaster                  |
| Wood               | particle board, siding                     |
| Wood Contaminants  | adhesives and resins, preservatives        |
| Miscellaneous      | batteries, tires                           |

Source: US EPA, 1995a

### 2.1.4 C&D Waste Generation

The U.S. Environmental Protection Agency estimated that 124 million metric tons of building-related C&D waste only (i.e., excluding waste from roadways and bridges, land clearing debris, and materials from excavation), or 1.2 kg per person per day, were generated in the U.S. in 1996 (US EPA, 1998a). The estimated per capita generation rate is approximately two-thirds that of the municipal solid waste (MSW) generation rate (1.8 kg per person per day) (US EPA, 1998b). Bossink and Brouwers (1996) reported that the C&D waste stream entering landfills is almost 20 to 29 percent of all solid waste in the United States. In Florida, C&D waste is the second largest fraction of the municipal solid waste stream following paper waste. It consisted of approximately 23% (or 5.5 million tons) of solid waste collected in the State (Figure 4-1)(FDEP, 1998).

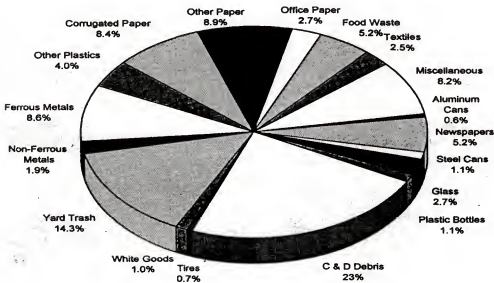


Figure 2-1 Florida Municipal Solid Waste Composition (Jan. 1, 1996 – Dec. 31, 1996)

(Source: FDEP, 1998)

While predictable annual generation rates for residential MSW have established (US EPA 1998b), C&D waste generation is more variable. One reason C&D generation is less well known is because C&D debris is typically not measured at scale. Sampling from a mixed waste stream is very difficult, time consuming, and costly. Also, many factors influence C&D waste generation rates. These factors include population level, economic growth, amount and type of construction activity, and the occurrence of natural disasters. Increasing population results in increased residential, commercial and institutional construction. Demand for schools, parking, and support structures increases as population increases. Any region that is economically well developed, or that is growing economically can expect to have greater construction activities, and hence greater C&D waste generation. Greater demolition occurs when a building is old or structurally weak. An older community or an old city, would represent a greater amount of old buildings, hence requirements for demolition or renovation in such a community will be greater. As roads and other structures lose structural integrity, C&D waste generation increases (Keller, 1993; Bossink and Brouwers, 1996).

#### 2.1.5 Composition of C&D Waste

The nature of leachate is determined largely by the amount and type of materials placed in a landfill. Although other factors such as geographical location of the landfill, the type of landfill operations, and moisture movement within the waste also affect contaminant leaching from the waste, the type and composition of waste in a particular waste stream influences the quality of leachate generated most. Thus, it is important to

understand the types and relative quantities of C&D waste that contribute to development of the leachate's properties.

Detailed waste composition studies have been performed for waste types such as MSW. Information of C&D waste composition, however, is limited. Nevertheless, several investigators have conducted a composition study for C&D waste stream (NAHB, 1995; NAHB, 1997; Metro, 1997; US EPA, 1998a). The following briefly summarizes some of the previous studies conducted to develop composition data for C&D waste.

#### 2.1.5.1 NAHB Study

The National Association of Homebuilders (NAHB) Research Center conducted waste composition studies at four residential construction sites from different locations in the United States: two sites in Maryland, one site in Oregon, and one site in Michigan (NAHB, 1995). Wood was the largest fraction followed by drywall (Table 2-3). The NAHB also provided waste assessment data from the demolition waste of a four-unit dwelling (NAHB, 1997). Concrete (or rubble) was the dominant component for the entire demolition debris, as shown in Table 2-3. Drywall was the second largest fraction of the waste stream.

#### 2.1.5.2 Metro Study

The Metropolitan Service District in Portland, Oregon examined the composition of C&D waste from three new residential construction sites, two residential renovation sites, and three residential demolition sites in Portland (Metro, 1997).

Table 2-3 Summary of Previous Composition Studies of C&amp;D Waste (by Mass)

| Components        | Residential Construction |                    | Residential Renovation <sup>2</sup> | Residential Demolition |                   | Demolition Non-Residential <sup>5</sup> |
|-------------------|--------------------------|--------------------|-------------------------------------|------------------------|-------------------|---|
|                   | NAHB <sup>1</sup>        | Metro <sup>3</sup> |                                     | Metro <sup>3</sup>     | NAHB <sup>4</sup> |   |
| Wood              | 42%                      | 67%                | 45%                                 | 42%                    | 14%               | 16%                                     |
| Drywall           | 27%                      | 20%                | 21%                                 | 0%                     | 17%               | 0%                                      |
| Metal             | 2%                       | 0%                 | 1%                                  | 2%                     | 0%                | 5%                                      |
| Plastics          | 2%                       | 0%                 | 0%                                  | 0%                     | 0%                | 0%                                      |
| Roofing           | 6%                       | 0%                 | 28%                                 | 0%                     | 3%                | 3%                                      |
| Brick or Concrete | 6%                       | 5%                 | 0%                                  | 24%                    | 65%               | 67%                                     |
| Miscellaneous     | 15%                      | 8%                 | 5%                                  | 32%                    | 1%                | 9%                                      |
| Total             | 100%                     | 100%               | 100%                                | 100%                   | 100%              | 100%                                    |

Source: 1. NAHB, 1995

2. Metro, 1997

3. Metro, 1997

4. NAHB, 1997

5. US EPA, 1998a



The largest component of the waste stream from the three new residential construction sites was wood (67%) followed by drywall (Table 2-3). In the residential renovation waste stream wood and drywall were major components of C&D waste composition with a substantial increase in the amount of roofing materials. By contrast, concrete was one of the major components in the waste from three residential demolition sites (Table 2-3).

#### 2.1.5.3 Rhines Inc. Study

R.W. Rhines, Inc also performed a waste composition study at 19 nonresidential (industrial / commercial) demolished buildings sites in Northwest area in the U.S. (US EPA, 1998a). Demolition waste contained a high percentage of concrete (67%) in the demolition waste stream (Table 2-3).

#### 2.1.5.4 Summary of Composition Studies

These studies demonstrate that the composition of C&D waste depends highly on the type of construction and demolition activities. However, some general conclusions can be drawn based on these studies. Construction waste is generally composed of waste scraps of a raw or new material used in the construction of various structures. Wood and drywall are the larger fractions of construction waste. Demolition waste is composed of various used materials. A large portion of the demolition waste stream is comprised of concrete and rubble.

In summary, the largest fractions of C&D waste stream are wood, drywall, and concrete. Other components often present in significant quantities include roofing

materials, cardboard, metals, insulation, asphalt shingles, and dirt. The C&D waste stream also contains plastics, glass, and other materials in smaller quantities. C&D waste may contain wastes materials with hazardous properties (e.g., adhesives, solvent containers, waste oils, treated or coated wood, and lead-based paint products). Most of the hazardous materials are contained in a very small fraction of the C&D waste stream (US EPA, 1995a).

## 2.2 C&D Waste Management

C&D waste used to be disposed of in a variety of ways, ranging from burning to burial onsite. However, as a greater emphasis has been placed on C&D waste and its proper disposal, these disposal practices have been widely abandoned in the United States. Most C&D waste generated in the United States is ultimately deposited in a designated C&D waste landfill. Remaining waste is either recycled, or disposed in municipal solid waste (MSW) landfills or in other non-permitted disposal sites (US EPA 1998a).

### 2.2.1 Land Disposal

Landfilling is the most common method of waste disposal for C&D waste. In 1994 a study done for the US EPA identified approximately 1,900 active C&D landfills in the United States (ERG, 1994). In Florida, the typical method for managing C&D waste is land disposal. Florida Department of Protection Agency (FDEP) reported that the state of Florida has 181 C&D debris landfills where approximately 2.8 million tons were disposed in 1996 (FDEP, 1998).

### 2.2.2 C&D Waste Recycling

C&D waste recycling is an attractive alternative to landfill disposal. In recent years, the recycling of C&D waste has evolved into a large and growing industry in the United States. Issues such as increasing disposal costs and the recycling potential of the many of the components in C&D waste stream have resulted in the start-up of a large number of C&D recycling operations (Spencer, 1990; Lee, 1991; Donovan, 1991; US EPA, 1998a). In 1996, it was estimated there were at least 1,800 operating C&D recycling facilities in the United States (Brickner, 1997). A growing number of companies hence formed to process these C&D materials into marketable products (Spencer, 1990). In 1996, a total of 43 C&D debris recycling facilities, which process materials generated from residential and commercial C&D sites, existed in Florida (FDEP, 1998).

Like other types of waste, the reasons for recycling C&D waste are to conserve material resources, save valuable landfill space and to protect the environment by limiting the potential for discharge of leached contaminants from disposal facilities to groundwater. C&D waste has a high potential for reuse once recovered and has easily identified sources. The materials most frequently recycled and recovered include concrete, metals, drywall, and wood. With a C&D recycling program that includes site separation a large portion of C&D waste can be recycled. However, not all C&D waste is recyclable and marketable, and must end up in a landfill disposal. The major barriers to recycling or reusing C&D waste include the cost of collecting and processing, the higher values of the recycled material, the unstable market for recycling products and the low tipping fee of C&D waste landfill disposal (US EPA, 1998a).

## 2.3 Landfill leachate and Waste Decomposition

This section discusses mechanisms of leachate formation in landfills, waste decomposition processes, and factors affecting leachate chemical composition. Much information to be discussed in this section is related to municipal solid waste instead of C&D waste since no literature regarding C&D waste decomposition is available.

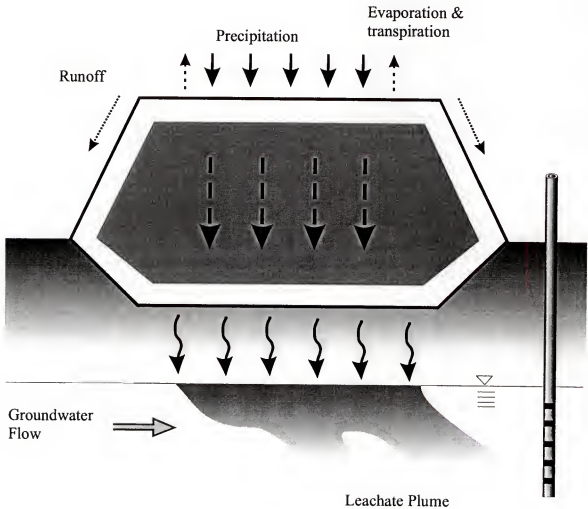
### 2.3.1 Mechanisms of Landfill Leachate Formation

Leachate is formed when moisture enters a landfill and percolates through the waste. The major source of percolating moisture is precipitation from the atmosphere. Other sources include groundwater intrusion into the landfill, runoff, and to a lesser extent, moisture within the waste at placement. Disposal of bulk liquids is currently banned from U.S. landfills. Figure 2-2 presents moisture movement in a landfill.

Precipitation from the atmosphere enters the landfill at the surface. Some of the precipitation evaporates, transpires through the vegetative cover, and forms surface runoff. The remaining moisture infiltrates the surface, fills void space and saturates the waste placed within a landfill. Once the field capacity (defined as the moisture content beyond which any increases in moisture will drain via gravity) is reached, the remainder of moisture moves downward, resulting in leachate formation. Leachate migration may also occur as a result of channeling through highly permeable pathways or voids in the waste.

When a liner and a leachate collection system is constructed at the base of the landfill, the leachate may be collected for disposal. The liner is designed as a barrier to intercept leachate and to direct to the leachate collection system. In the absence of these

systems, the leachate migrates into the underlying soil and groundwater. The quality and quantity of leachate produced is a function of climate, type of landfill management and operations (e.g., waste pretreatment, type of cover soil, leachate recirculation, and landfill configuration), type of waste in a landfill, and the microbial activities occurring in a landfill.



**Figure 2-2. Moisture Movement in a Landfill and Leachate Formation**

### 2.3.2 Waste Decomposition

During infiltration and percolation processes, contaminants are mobilized into the liquid phase through a complex process including all of the different physical, chemical, and biological decomposition processes occurring within the landfill. Waste decomposition has a direct effect on contaminant movement by breaking down the waste into soluble compounds and exposing more surface area to percolating liquids (McGinley and Kmet, 1984). Solubilization occurring within a landfilled waste also plays a major role in the movement of metals and ions resulting from metallic wastes and non-biodegradable components (e.g., concrete, minerals, glass, etc). Many researchers have attempted to model these processes and the resultant contaminant release from municipal solid waste (Qasim and Burchinal, 1970; Raveh and Avnimelech, 1979; Ham, 1980; Lu et al., 1981; Straub and Lynch, 1982a; Straub and Lynch, 1982b; McGinley and Kmet, 1984; Farquhar, 1989; Gau and Chow, 1998).

#### 2.3.2.1 Physical, Chemical, and Biological Decomposition Processes of Waste

Physical decomposition of solid waste occurs as a result of the breakdown and movement of the waste components by physical degradation and by the rinsing and flushing action of moisture movement. Chemical decomposition processes include ion exchange, complexation, ionization, acid-base reactions, oxidation-reduction, and the precipitation of waste components. These processes result in changes of chemical characteristics of waste components and increased mobility, thereby enhancing the rate at which the landfill becomes more chemically uniform (McBean et al., 1995).

Despite the fact that solid waste deposited in a landfill decomposes by a combination of physical, chemical, and biological processes, biological decomposition is a dominant decomposition process in a landfill containing a high fraction of biodegradable waste (e.g. MSW). The biological decomposition processes occur with naturally present microorganisms in a landfill. The biological processes include hydrolysis of complex organic matter, fermentation, destructive metabolism, action of sulfate-reducing bacteria, and nitrification. This decomposition controls the physical and chemical processes via its effect on such variables as pH and redox potential (Ross, 1990). However, interdependencies among these processes also exist. For example, the physical and chemical processes play a major role in the availability of nutrients essential for biological action. Table 2-4 lists examples of the three decomposition processes occurring within a landfill.

**Table 2-4 Physical, Chemical, and Biological Decomposition Processes of Solid Waste Landfill**

| <b>Physical Decomposition Processes</b> | <b>Chemical Decomposition Processes</b> | <b>Biological Decomposition Processes</b> |
|---|---|---|
| Sorption                                | Complexation                            | Fermentation                              |
| Filtration                              | Ion exchange                            | Hydrolysis                                |
| Coagulation                             | Ionization                              | Nitrification                             |
|   | Acid-base reactions                     | Sulfate-Reduction                         |
|   | Oxidation-reduction                     | Destructive metabolism                    |
|   | Precipitation                           |   |

Source: Ross, 1990

### 2.3.2.2 Waste Decomposition Phase

Various biologically mediated processes decompose solid waste within a landfill. The biodegradation of the waste is typically described as an anaerobic decomposition process, similar to an anaerobic digester in a wastewater treatment plant. Research on anaerobic digestion has helped to describe the anaerobic decomposition process occurring in a landfill as several major steps (McCarty, 1981; Archer and Robertson, 1986; McBean et al., 1995).

Five phases have been identified during the previous decomposition studies of municipal solid wastes. These phases are shown in Figure 2-3. The phase diagram presents a convenient description of the decomposition phases of waste undergoing stabilization in a landfill and the chemical characteristics of selected parameters in both leachate and gas.

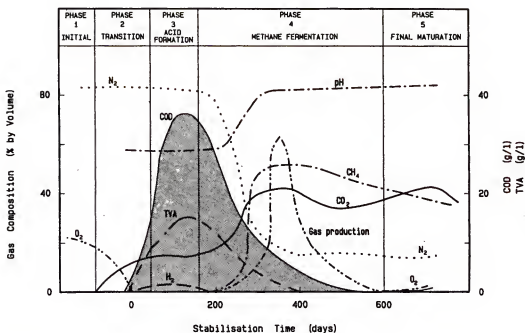


Figure 2-3 Decomposition Phases of Municipal Solid Waste at a Landfill

(Source: Pohland and Harper, 1986)



- **Phase 1: Aerobic Decomposition**

Aerobic decomposition begins during the initial placement of the waste. Although most of the waste may be too dry for microbial activity, some of the highly biodegradable organic fractions (e.g., food waste, biowaste) can be readily biodegraded to partially degraded organics, carbon dioxide, water and heat. However, the period of this composition phase is fairly short relative to subsequent anaerobic decomposition. As the initial oxygen content is consumed, the first anaerobic phase of decomposition begins. In this phase leachate is not usually produced because the waste has not yet reached field capacity. Most of the leachate generated results from channeling through void space or high permeable pathways in the waste. Thus leachate is typically composed of particulate matter entrained by the percolating water, soluble salts present in the waste, and small amounts of soluble organics (McBean et al., 1995).

- **Phase 2: Transition**

A transition from aerobic to anaerobic condition occurs when the moisture content of the waste is high enough to reach field capacity, which results in the generation of leachate. During the transition phase, the primary electron acceptors change from oxygen to sulfate and nitrate. Oxygen is then displaced by carbon dioxide in the gas (Pohland et al., 1986). Leachate contains some intermediates (e.g., fatty acids) resulting from anaerobic decomposition of organic waste. Consequently, it increases organic strength in the leachate.

- **Phase 3: Anaerobic Decomposition: Acid Formation**

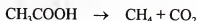
The acid formation phase occurs when the complex organic wastes are converted to simpler, soluble polymers, like proteins, carbohydrates and lipids. After the hydrolysis of complex organics, fermentation of these organics takes place, yielding biomoners like long-chain organic acids, alcohols, sugars, amino acids, and high molecular fatty acids (Parkin and Owen, 1986; Speece, 1983).

The long-chain organic acids and alcohols are oxidized to acetate and hydrogen amino acids, while sugars are converted into either intermediate by-products, such as propionic, n-butyric and other volatile acids, or directly fermented to acetic acid (Parkin and Owen, 1986; Speece, 1983; Harper and Pohland, 1987; Dubourguier et al., 1988). Ammonia, hydrogen, and carbon dioxide are also produced during this phase.

Because of an increase of organic acids, a sharp decrease of pH in leachate takes place, ranging from 5.5 to 6.5. In this phase, oxygen demand in leachate increases as a result of the breakdown of waste materials. Anaerobic biological activity can also lower the value of oxidation-reduction potential (ORP) in leachate. Under these increasingly reduced conditions and decreased pH, mobilization and complexation of metal species take place along with a chemically aggressive leachate (McGinley and Kmet, 1984; Gould et al., 1988; Alker et al., 1995). Because the highly contaminated leachate assists in dissolution of other contaminants in the waste due to ionic strength, leachate may contain high concentration levels of ions, sometimes actually exceeding the solubility limits of ions.

- **Phase 4: Anaerobic Decomposition: Methane Formation**

As the biodegradation of waste in a landfill continues, the landfill becomes more reduced, and anaerobic methanogenic bacteria gradually become established and dominant (known as methanogenesis). These organisms produce carbon dioxide, methane, and water after acetate cleavage as follows:



The methanogenic bacteria start to consume the simple organic compounds, producing methane, carbon dioxide, and water. In addition to methane and carbon dioxide, hydrogen sulfides and nitrogen are also produced from the microbial processes of denitrification and sulfate-reducing bacteria. At this stage, the landfill has the highest rate of microbiological activity.

The pH of leachate ranges from 7 to 8 as a result of consumption of the organic acids generated during Phase 3 acid formation decomposition. Leachate becomes chemically less aggressive, containing relatively low organic strength and decreased dissolved solids. However, some of inorganic ions (e.g., sodium and chloride) often continue to leach in significant quantities into leachate over many years.

- **Phase 5: Final Maturation**

A final maturation phase following active biological decomposition of waste in a landfill is characterized by fairly constant gas production, reinstatement of natural environmental conditions, and an increase of oxidation and reduction potential.

In summary, MSW landfill leachate may contain different chemical constituents depending on the phase of the waste decomposition. The monitoring of chemical constituents in leachate reflects the intermediate or end products of the various decomposition processes occurring in a landfill and the degree of completion of the overall waste decomposition process. However, these phases are highly interdependent and overlapped. In full-scale MSW landfills, no single phase may exist to describe waste decomposition progress, but rather a family of different ages. Also, this phase study mainly focuses on the decomposition of organic waste placed in a landfill. If wastes do not comprise large percentage of organic waste components (e.g., ash monofills, C&D waste landfills), this phase description should not be directly applied to the waste decomposition study.

### 2.3.3 Factors Affecting Leachate Chemical Composition

Leachate chemical composition in a landfill is a function of numerous factors. These factors include waste age, the type and composition of waste, waste depth, moisture content, and landfill operations (e.g., waste pretreatment, cover soil type, leachate recycling). The mechanisms and extent to which these factors influence contaminant leaching cannot be easily distinguished because they are interrelated. In addition, because landfill heterogeneities exist, accurate quantification of these factors and their impacts on leachate composition is not an easy task. Nonetheless, the influence of these factors on leachate composition has been studied by a number of researchers in laboratory-scale and field-scale landfills (Raveh and Avnimelech, 1979; Lu et al., 1981; Pohland et al., 1986; Reitzel et al., 1992; Chen, 1996; Armstrong and Rowe, 1999; Öman

et al., 1999). The following sections briefly discuss some of the factors affecting leachate chemical composition.

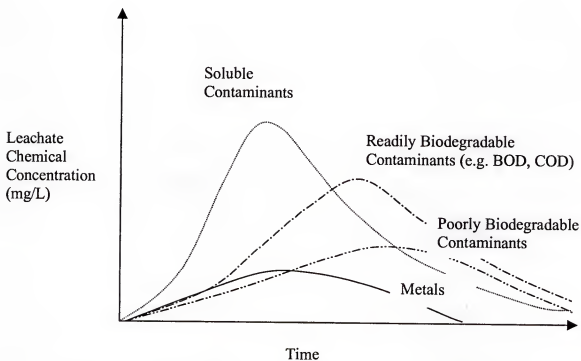
#### 2.3.3.1 Waste Age

Among the factors mentioned above, waste age was found to be the most relevant factor affecting MSW leachate composition (Reitzel et al., 1992). The age reflects the degree of stabilization of the landfilled waste. As waste decomposition progresses over time, different end products are leached into the liquid phase. Significant variability of leachate composition exists as a function of time in a landfill.

However, certain trends in leachate concentration levels for some chemical parameters can be observed as a function of time. Contaminant concentrations in leachate generally increase to a peak level, and then gradually decline over time as the landfill ages. Since there are finite amounts of contaminants within the waste, leaching rates of contaminant begin to level out as depletion occurs. Rates of incline and decline vary over time as well as by the type of contaminant. Figure 2-4 illustrates contaminant leaching trends for several categorized contaminants over time.

In municipal landfill leachate, for example, the readily soluble chemicals (e.g., cations and anions from salts) reach a peak early and rapidly decline over time. Organic constituents such as COD and BOD from waste decomposition peak next, stay a relatively constant level for a lengthy period of time, and then gradually decline as the remainder of waste decomposes. Poorly biodegradable organics are slowly converted to partially biodegradable organic compounds, increasing to a plateau and tend to remain at constant concentrations over a long period of time. Temporal trends of metal concentrations in leachate vary significantly depending on the type of metal of interest as

well as conditions within the landfill such as chemical and biological activity, pH, and the degree of waste decomposition (Alker et al., 1995). In general, metal concentrations in leachate increase gradually over time and then decline as depletion of metals occurs. It is commonly known that some metals tend to react with sulfides to form insoluble metal precipitates, resulting in reduction of metal concentrations in leachate.



**Figure 2-4 Generalized Leaching Patterns of Categorized Pollutants in a Landfill**

(Source: Modified from McBean et al., 1995)

#### 2.3.3.2 Waste Composition

Knowledge of the composition of the waste deposited in landfills is of great importance because waste type and composition directly influence the chemical composition of leachate. For example, high levels of biodegradable organic components

relate directly to the presence of high levels of organic constituents in leachate. Likewise, wastes composed of primarily inorganic, non-degradable components (e.g., ash slag, metals, bulky waste, and industrial waste) are responsible for ion and metal mobilization and therefore, increased inorganic constituent concentrations in leachate.

#### 2.3.3.3 Waste Depth

The characteristics of leachate can also vary with the depth of waste. Increases in waste depth allow the moisture flow to approach the solubility limits of constituents as the contact time between the solid and liquid phase increases. As a result, the leachate strength typically increases with the depth of the waste (Qasim and Burchial, 1970; Lu et al., 1984; McGinley and Kmet, 1984; Karnchanawong et al., 1995; Öman et al., 1999).

#### 2.3.3.4 Moisture Content

The quality of the leachate is influenced by the rate of moisture addition to landfilled wastes since the moisture addition rate affect solute dissolution, microbial activity, and particle entrainment (Emcon, 1975; Karnchanawong et al., 1995). At low moisture application rates, anaerobic microbiological activity becomes a significant factor in governing organic strength in leachate. However, at higher flow rates, soluble organics and even microbial cells may be flushed from the waste (McBean et al., 1995). Leachate recycling increases biological activities and thus reduces pollutant concentration while increasing the mineralization of wastes (Pohland, 1980).

#### 2.3.4 Leaching Experiments: Tools of Landfill Leachate Simulation

Many investigations have been conducted on the process of contaminant leaching in landfills since the late 1960's. The investigators have collected leachate from waste under various conditions and have measured their pollutant concentrations. Some studies have involved actual pilot or field-scale landfill sites (Lu et al., 1984; Reitzel et al., 1992; Chen, 1996; Armstrong and Rowe, 1999; Öman et al., 1999), but the majority have utilized laboratory-scale columns, also called lysimeters, filled with compacted solid waste (Qasim and Burchinal, 1970; Fungaroli and Steiner, 1979; Raveh and Avnimelech, 1979; Wigh, 1979; Walsh and Kinman, 1981; Ham and Bookter, 1982; Jones and Malone, 1982; Pohland, 1983; Gould et al., 1988; Ehrig, 1991; Kouzeli-Katsiri et al., 1993; Karnchanawong et al., 1995). The following discussion describes laboratory and field-scale leaching experiments as a tool of landfill leachate simulation. Most studies have been conducted using municipal solid waste.

##### 2.3.4.1 Laboratory Leaching Experiments: Batch and Lysimeter Studies

Various laboratory techniques have been reported for assessing the leachability of waste and are generally grouped into batch and column (or lysimeter) leaching methods. A batch leaching method involves the mechanical mixing of a unit volume of water or an alternative solution, with a unit mass of waste. This method is often used for its ease of operation and low experimental variation. A lysimeter leaching test involves the continuous flow of liquid through a fixed bed of waste. Leachate generated by the lysimeter method is reportedly more representative of leachate derived from a disposal site than leachate from the batch method. The lysimeter test can provide information on



the release of contaminants over time. While liquid to solid (or waste) ratio is typically 20:1 during a batch test, different liquid to solid ratios, specifically lower liquid to solid ratio, can be applied to the lysimeter test. The lysimeter test can simulate contaminant leaching resulting from biological decomposition of waste.

However, lysimeter tests are not without disadvantages. Lysimeter procedures appear to be somewhat less precise than batch methods. Lysimeter devices are more difficult to operate because of the need to maintain a constant, usually low flow rate of liquid. Certain wastes are difficult to examine in lysimeter tests because of the size of the individual particles that comprise the waste such particles can be either too large, resulting in uneven column packing and flow distribution, or too small, resulting in excessive resistance to leachate flow. Finally, wall effects or internal cracks can cause uneven flow distribution, which may be difficult to detect (Jackson and Bisson 1984). Batch experiments can be used to provide a quick, inexpensive, and alternative method for estimation of the contaminants released by solid wastes, and their concentration.

#### 2.3.4.2 Batch Leaching Tests

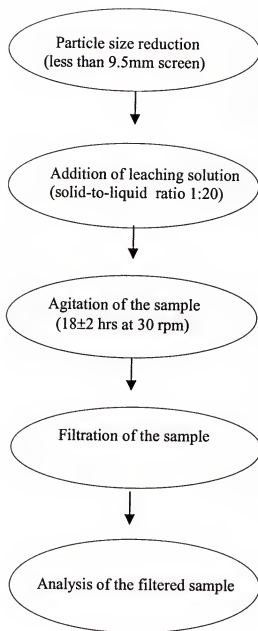
Although a number of different batch leaching tests are available, the most commonly employed leaching test used in the United States is the Toxicity Characteristics Leaching procedure (TCLP; EPA SW-846 Method 1311, US EPA, 1994). This is the assay required to determine whether a solid waste is hazardous by the toxicity characteristics. The TCLP was designed to simulate conditions in an anaerobic landfill. Consequently, it tends to represent worst case leaching conditions in a landfill. The EPA has also developed the Synthetic Precipitation Leaching Procedure (SPLP; EPA SW-846

Method 1312, US EPA 1994). The SPLP is performed in the same manner as the TCLP, but simulated acid rainwater is employed.

While batch tests may not be representative of actual conditions in a landfill, they are the most widely available, utilized, and standardized tests for evaluating the leaching potential of solid wastes. The batch tests are also valuable from the perspective of generating information useful for predicting contaminant leaching as a function of a number of different variables. The following variables can be investigated in a more rapid fashion using batch tests versus lysimeter tests; the effect of different water to solid ratio, leaching time, particle size effect, and leaching solution pH. Figure 2-5 presents a typical batch leaching procedure.

#### 2.3.4.3 Lysimeter Experiments

Numerous researchers have attempted to unravel the processes controlling contaminant leaching at municipal solid waste landfills and simulate landfill leachate under controlled conditions in lysimeters (Qasim and Burchinal, 1970; Emcon, 1975; McCabe, 1975; Pohland, 1975; Fungaroli and Steiner, 1979; Raveh and Avnimelech, 1979; Ham, 1980; Walsh and Kinman, 1981; Ham and Bookter, 1982; Jones and Malone, 1982; Pohland, 1983; Attal et al., 1992; Kouzeli-Katsiri et al., 1993; O'Keefe et al., 1993; Pohland et al., 1993; Blakey et al., 1995; Chugh et al., 1995; Karnchanawong et al., 1995; Yuen et al., 1995; Ehrig, 1996). These waste lysimeters are scale-model landfills constructed so that the leachate generated by the lysimeters can be collected and analyzed for the chemical parameters of interest. No standardized protocol is in use for the lysimeter (column) test in the United States.



**Figure 2-5 A Typical Leaching Procedure of Batch Test**

The sizes of lysimeter used for leaching experiments in the literature exhibited greater variability, ranging from a cubic yard to several hundred yards. Some lysimeters have been constructed outside to allow exposure to the natural environment, others in laboratory-controlled conditions. Under laboratory conditions, leaching solution is added to simulate precipitation and induce moisture flow, which is similar to a full-scale landfill. Factors affecting leachate quality such as moisture application rates, waste composition and density, and waste depth have been evaluated in the lysimeter studies (Qasim and Burchinal, 1970; Emcon, 1975; McCabe, 1975; Fungaroli and Steiner, 1979; Raveh and Avnimelech, 1979; Ham, 1980; Walsh and Kinman, 1981; Ham and Bookter, 1982; Karnchanawong et al., 1995).

#### 2.3.4.4 Field Test Cell and Full-scale Investigations

In attempting to better characterize the nature of landfill leachate, many field test cell and full-scale landfill investigations have been conducted on mainly municipal solid wastes (Johansen and Carlson, 1976; Wigh and Brunner, 1984; Emberton, 1986; Robinson and Gronow, 1993; Chen, 1996; Lo, 1996; Armstrong and Rowe, 1999; Fatta et al., 1999; Öman et al., 1999; Urbini et al., 1999). A real landfill is a complex and dynamic environment with chemicals being dissolved and precipitated by the fluid, which moves through the landfill. Many empirical studies have found that the characteristics of landfill leachate are highly variable.

### 2.4 C&D Waste Leachate

To date, only a limited number of studies have been conducted to examine the characteristics of leachate resulting from C&D waste land disposal. Previous research

includes investigations of field sites that relate to C&D waste leachate (Hamel, 1989; Norstrom et al., 1991; Interpoll, 1992; WMI, 1993), a number of surveys on existing regulatory and compliance information from C&D debris landfills in the U.S. (NADC, 1994; US EPA 1995a; US EPA 1995b), and laboratory lysimeter studies (Ferguson and Male, 1980; Thurn, 1997),

This section provides a literature review of C&D waste landfill leachate throughout the country. Previous studies on C&D leachate characteristics and the identification of potential contaminants of groundwater quality from C&D landfills are of particular focus.

#### 2.4.1 Field-Scale Leachate Study

##### 2.4.1.1 Sweet and Fetrow Study

Sweet and Fetrow (1975) conducted a study regarding the potential impact of wood waste disposal. They investigated groundwater problems resulting from wood waste landfills near domestic water supply wells in Oregon. Approximately 3,000 tons of wood waste were disposed in a large gravel borrow pit that was 10 to 12 feet deep and 2 to 3 acres in area. Water samples were collected from 23 groundwater monitoring wells to characterize wood waste leachate and determine the extent of leachate contamination. Five analytical parameters were tested: pH, total acidity, lignin-tannin, total iron, and manganese.

An initial drop in pH and an increase in total acidity of the contaminated groundwater were observed as a result of the leaching of organic acids from the wood

waste. The acidity in turn caused dissociation of some iron and manganese from alluvial substrata through which the contaminated groundwater was passing (Sweet and Fetrow 1975). High concentrations of lignin-tannin content in leachate were observed, ranging up to 7.4 mg/L. Odors and a yellow-brown discoloration in the collected well water samples were observed. The approximate area affected by the leachate-contaminated groundwater ranged from approximately four acres in 1972 to about fifteen acres in 1973. While the wood waste in this study was not C&D wood waste, it does provide insight regarding the impact of one of the larger components (i.e. wood) of the current C&D waste stream.

#### 2.4.1.2 Hamel Study

In Connecticut, leachate produced from bulky waste landfills was characterized to assess impacts from bulky waste landfill sites (Hamel, 1989). Bulky waste includes C&D debris and land clearing debris. The study was conducted over a period of six months and samples were obtained from five different bulky waste landfills in Connecticut. The leachate samples were mostly obtained from seeps at the base of the landfills. A total of 15 samples were taken from the landfills and analyzed for conventional parameters and heavy metals (Hamel, 1989).

The constituents in leachate that exceeded the secondary maximum contaminant levels (SMCL) for drinking water standards at least once included pH, TDS, iron, and manganese. Eight samples exceeded the primary maximum contaminant levels (MCLs) for cadmium and 13 samples exceeded the MCL for lead (Hamel, 1989).

#### 2.4.1.3 Norstrom et al. Study

Norstrom et al. (1991) studied three lined C&D waste landfills in Texas to identify any elevated chemical constituents for tracking in a groundwater monitoring program. The results were compared with MSW leachate. Leachate wells were installed at each C&D waste site.

The study found that one or more samples exceeded the secondary drinking water standards for zinc, iron, TDS, manganese and sodium. The levels of barium, lead, manganese and zinc in the C&D leachate also exceeded the limits for a wastewater treatment plant ordinance for the city of Houston. High COD, low pH, and relatively low metals concentrations in the C&D leachate were observed, indicating that the age of C&D landfill was relatively young.

Comparison between MSW and C&D leachate constituent levels showed that C&D leachate typically fell within the published MSW constituent ranges. In most cases, C&D leachate concentration ranges fell below typical maximum MSW concentrations. The C&D maximum concentrations were usually less than one-half the MSW maximum concentration (Norstrom et. al, 1991). The investigators concluded that the C&D leachate, when compared to natural groundwater quality in the area, posed a threat to groundwater quality if not properly contained (Norstrom et. al, 1991).

#### 2.4.1.4 Interpoll Study

A study of C&D waste leachate was conducted for a clay-lined C&D landfill in Minnesota (Interpoll, 1992). Since 1989, the landfill has accepted only C&D waste. Eight

leachate samples were collected during the period 1990 through 1992, and analyzed for conventional water quality parameters, metals, trace organic compounds and polycyclic aromatic hydrocarbons (PAH). Constituents in the landfill leachate that exceeded the secondary drinking water standards at least once include chloride, iron, manganese, nitrate, nitrite, and total dissolved solids. A number of trace organic compounds such as methylene chloride, trichlorofluoromethane, and some of PAHs were detected, but they did not exceed the applicable standards (Interpoll, 1992). The study concluded that the concentrations of constituents in leachate generated from the C&D landfill is significantly lower than MSW leachate.

#### 2.4.1.5 WMI Study

A study was conducted by Waste Management Incorporated (WMI) to characterize the composition of leachate from three C&D waste landfills (WMI, 1993). WMI planned to use the results of this work to determine if liners were needed for C&D waste landfills. The study site included one site in Kentucky, one in Michigan, and one in Massachusetts. Leachate samples were collected and analyzed for a number of parameters, including volatile organic compounds, semi-volatile compounds, metals, and conventional water quality parameters.

The investigators concluded that none of the leachate from the four C&D waste landfills would be classified as hazardous waste because all samples passed the TCLP test. A number of volatile organic compounds and semi-volatile compounds were detected in the leachate, but levels never exceeded the maximum contaminant levels



established by the National Primary Drinking Water Standards (CFR, 1997). A number of metals detected included arsenic, barium, chromium, lead, nickel, and zinc.

Concentrations of iron, zinc, total dissolved solids, and sulfates did exceed the Secondary National Drinking Water Standards at least once in leachate samples. Because the leachate contained elevated levels of some contaminants, the study concluded that certain engineering controls should be implemented at C&D landfills. The authors recommended that liners, leachate collection systems, and groundwater monitoring wells should be installed at landfills that accept C&D waste (WMI, 1993).

#### 2.4.1.6 Weber Study

Weber (1999) conducted a field test cell leaching experiment for residential construction waste collected from residential construction sites to characterize C&D leachate. Four construction waste test cells were built at the Southwest Landfill site in Alachua County, Florida. The dimensions of each test cell measured approximately 30 feet long by 20 feet wide. The maximum depth of each cell was approximately at 6 feet. A bottom liner and leachate collection system were installed in each cell to provide a means of intercepting and collecting leachate.

Leachate samples were collected for analysis of volatile organic compounds (VOCs), semi-volatile organic compounds (semi-VOCs), metals, and conventional water quality parameters. Leachate sampling of Cell 1 and Cell 2 was conducted over 161 days. Cell 3 and Cell 4 were operated over a period of 140 days.

When contaminant concentrations measured in leachate from this study were compared to drinking water standards, a few exceeded appropriate limits. The

constituents included aluminum, arsenic, copper, manganese, iron, sulfate, and total dissolved solids. Arsenic was the only primary drinking water standard that was exceeded. Calcium and sulfate were predominant ions in the leachate. This resulted from the soluble characteristics of gypsum drywall. Pollutants in the leachate that exceeded the EPA secondary drinking water standards by the greatest magnitude were manganese, followed by iron. The most likely source of chromium and arsenic was from chromated copper arsenate (CCA)-treated wood. No volatile or semi-volatile organic compounds were detected at elevated levels in the leachate.

#### 2.4.2 Survey Leachate Study

##### 2.4.2.1 NADC Study

The National Association of Demolition Contractors (NADC) contracted the consultant firm of Gershman, Bricker & Bratton (GBB) to collect leachate data from C&D waste landfills around the United States and examine the appropriate management and/or disposal techniques for C&D waste (NADC, 1994). Since leachate quality from C&D waste landfills had never been adequately researched, GBB decided to investigate the environmental history of rubble fills or C&D waste landfills around the country. GBB sent letters to each State requesting information and data on any leachate test results submitted to the state as part of operational monitoring activities.

The investigators concluded that leachate from C&D landfills was not comparable with MSW leachate, and therefore, C&D landfills should not be subjected to the same regulations. The study also concluded that C&D landfills that meet the following

guidelines would not pose a significant threat to the environment (NADC, 1994): 1) train personnel who inspect all incoming waste loads for unsuitable waste; 2) develop leachate containment systems consisting of either suitable soil conditions; compaction of suitable soil, or other containment systems; 3) develop groundwater monitoring systems; 4) require financial assurance.

#### 2.4.2.2 US EPA Study 1

In 1996, The US EPA promulgated a rule addressing non-municipal facilities that may receive hazardous wastes from conditionally exempt small quantity generators (CESQG's) (Federal Register, 1996). This rule established standards pertaining to location restrictions, groundwater monitoring and corrective action. The rule did not require that such facilities be lined.

A report prepared in support of EPA's rulemaking (US EPA 1995a) involved collection of C&D leachate data from the literature, including the NADC report (NADC, 1994) and a small number of readily available reports (Hanrahan, 1994; Lambert and Domizio, 1993). The EPA report used parameter-specific regulatory and health-based benchmarks as a basis for screening potential risks. The Safe Drinking Water Act's National Primary and Secondary Drinking Water Standards were used for comparison when available.

Based on the number of landfills where a benchmark was exceeded, and a comparison between the median and the benchmark, the report authors concluded that seven parameters were "potentially problematic." The seven parameters of concern

included 1,2-dichloroethane, methylene chloride, cadmium, lead, manganese, iron, and total dissolved solids. The benchmarks for iron, manganese, and total dissolved solids are secondary maximum contaminant levels (MCLs) set to protect water supplies for aesthetic reasons (e.g., taste) rather than for health-based reasons. None of the remaining four parameters exceed the health-based benchmarks by a factor of ten or more.

The EPA investigators believed that leachate would be diluted by a factor of ten by the time it reached any groundwater monitoring wells or drinking water wells downgradient of a C&D waste landfill. If the leachate was not at least ten times greater than the applicable groundwater standard, the groundwater contamination resulting from the leachate would not exceed the applicable standards. Thus, the EPA did not believe that any of the seven parameters listed above would pose a problem at C&D waste landfills (US EPA, 1995a).

#### 2.4.2.3 US EPA Study 2

The US EPA also published a survey of “damage cases” for C&D landfills (US EPA, 1995b). A damage case was defined as an increase in constituent levels above background, or an exceedance of an applicable regulatory standard or criteria (US EPA, 1995b). The purpose of the study was to determine whether the disposal of C&D waste in landfills led to the contamination of groundwater, surface water or ecological resources. The study also examined whether the environmental damages could be attributed to specific aspects of the site, such as types of wastes received, design and operating practices, and environmental setting/location (US EPA, 1995b). Eleven landfills from the

states of New York, Virginia and Wisconsin were included in this report as damage cases.

Elevated levels of many inorganic constituents were found in the groundwater monitoring wells. Constituents that exceeded either state or federal groundwater protection standards most frequently were total dissolved solids (TDS), manganese, sodium, pH and sulfate. Sodium exceeded New York State's applicable standards by a factor of 10 or more (US EPA, 1995b).

This study concluded that the contamination from the C&D landfills more likely poses a threat to the aesthetic quality of the drinking water, rather than human health. Although the study demonstrated that individual C&D debris landfills can lead to groundwater and surface water contamination, it was difficult to determine the degree to which the sites are representative of a typical C&D landfill. Among approximately 1,800 C&D debris landfills operating throughout the U.S. at that time, only 11 sites were cited in this report. The limited number of damages cases and the limited data on C&D facilities in general made it difficult to determine the degree to which C&D facilities threaten human health and the environment. Because individual damage cases appear to be limited in occurrence, the EPA believed that C&D facilities did not currently pose significant risks (US EPA, 1995b).

#### 2.4.2.4 Melendez Study

Melendez (1996) reviewed the available data on leachate generated from C&D waste landfills around the country and conducted a statistical analysis of the data. Based on the statistical analysis, the following parameters in C&D leachate were determined to

present a potential risk to human health and the environment: methylene chloride, 1,2-dichloroethane, cadmium, lead, iron, TDS, manganese, sulfate. These parameters exceeded primary groundwater standards, secondary groundwater standards, and/or guidance concentrations for groundwater. A number of parameters that do not have primary or secondary drinking water standards were also observed in high concentrations at some sites. These parameters, such as biological oxygen demand or total organic carbon, may also impact groundwater quality (Melendez, 1996).

#### 2.4.2.5 Thurn Study

Thurn (1997) summarized leachate data from five lined Class III landfills in Florida (Table 2-5). In Florida, Class III landfills receive yard trash, C&D debris, waste tires, asbestos, carpet, cardboard, paper, glass, plastic, and furniture other than appliances (62-701.340) (FAC, 1997). Since Class III landfills often accept large amounts of C&D waste, leachate data from the Class III sites were compared with laboratory C&D leachate (Thurn, 1997). Data was obtained from Florida Department of Environmental Protection (FDEP) agency branch offices. In this study, the parameters in leachate that often exceeded either primary or secondary maximum contaminant levels (MCL) for drinking water were TDS, chloride and sulfate.

Table 2-5 A Summary of Leachate Data from Class III Landfills in Florida

| Parameter                               | Dyer        | Haines      | NCRRF       | Pitts      | West Pasco  |
|---|-------------|-------------|-------------|------------|-------------|
| Temperature (°C)                        | 24.7 - 31.9 | -           | 22.9 - 29.8 | 26.4-27.1  | 19 - 31.4   |
| pH                                      | 5.91 - 7.84 | -           | 6.46 - 7.27 | 7.0 - 7.28 | 6.27 - 6.49 |
| Conductivity (um/cm)                    | 1000-5090   | -           | 1944-7360   | -          | 1809 - 2716 |
| TDS (mg/l)                              | 752 - 2730  | 6600 - 6730 | 1140-6000   | -          | -           |
| COD (mg/l)                              | 106 - 1000  | -           | 101 - 1040  | -          | -           |
| TOC (mg/l)                              | -           | -           | 359         | -          | -           |
| Alkalinity (mg/l<br>CaCO <sub>3</sub> ) | 385 - 2219  | -           | -           | -          | -           |
| Ammonia-N (mg/l)                        | 14.9 - 207  | -           | 14.6 - 262  | 0.02 - 6.6 | -           |
| Calcium (mg/l)                          | 140 - 364   | -           | 144 - 740   | -          | -           |
| Magnesium (mg/l)                        | 18.9 -55.8  | -           | 55.2 - 132  | -          | -           |
| Potassium (mg/l)                        | -           | -           | 160 - 390   | -          | -           |
| Sodium (mg/l)                           | 52.3 - 307  | 1160 - 1500 | 56.0 - 540  | -          | 122 - 310   |
| Chlorides (mg/l)                        | 51.1 - 984  | 2600 - 2980 | 91.4 - 5720 | 10 - 29    | 166 - 468   |
| Fluoride (mg/l)                         | 0.11 - 2.0  | -           | 0.23 - 0.65 | -          | -           |
| Nitrate (mg/l)                          | <0.01 - 2.7 | -           | 0.01 - 0.48 | 0.21-0.26  | -           |
| Sulfate (mg/l)                          | <1.0 - 918  | -           | 38.0 - 420  | 51-1300    | 232         |

Source: Thurn, 1997

#### 2.4.3 Laboratory-Scale Leachate Study

Laboratory research has focused on leachate characterization from either predominant demolition components or typical C&D waste in laboratory-scale simulated landfills. Only two laboratory-scale C&D leachate studies are available.

##### 2.4.3.1 Ferguson and Male Study

Ferguson and Male (1980) investigated C&D leachate study from both laboratory and field studies to assess the potential for contamination from demolition waste disposal. A laboratory study involved two leaching lysimeters, each with a different composition of demolition waste. The lysimeters were constructed from two steel drums that were joined at the base of each drum. The height of the lysimeter was 5.8 ft and the inner diameter was 1.87 ft. Each of these lysimeters was lined with 6 mil polyurethane liners. A 3-inch gravel filter was placed at the bottom of the lysimeter apparatus (Ferguson and Male, 1980).

One lysimeter contained 50 % (by volume) masonry waste and only a small fraction of wood. The other lysimeter contained 50 % (by volume) wood waste and only a small fraction of masonry. The remaining volume of each lysimeter was filled with the other elements of demolition waste, such as plaster, roofing, floor tile, ceiling tile, insulation, electrical wiring, cast iron, iron, galvanized steel, upholstery, aluminum, and copper. The two lysimeters were operated under unsaturated conditions. The volume of water added to the lysimeters each week was equivalent to 2.5 cm of distilled, deionized water. This leaching solution was acidified to a pH of 4.50 to simulate rainwater



conditions (Ferguson and Male, 1980). The samples were analyzed for conventional water quality parameters, metals and lignin-tannin.

The results during the sixth week of the experiment are shown in Table 2-6.

Leachate in the laboratory study was found to have a slightly lower pH, alkalinity, and hardness, and a slightly higher conductivity than the field results. Metals were observed in the same range as encountered in the field samples. Leachate in the field and laboratory studies contained high concentrations of alkalinity, hardness, iron, and manganese. The authors concluded that demolition waste should be disposed properly to reduce the possible degradation of both ground and surface water quality.

The major goal of this laboratory study was to determine the parameters leached from different compositions of demolition waste and to provide the maximum concentrations of these parameters. This study did not evaluate any temporal changes in leachate quality to characterize the leachate. Therefore, the results provide only a snapshot of the C&D waste leachate at specific point where all the parameters tested leveled off at the sixth week.

Also, this laboratory study attempted to simulate leachate impacts on the environment assuming the selected composition for demolition waste at a field site. Therefore, the characteristics of leachate generated from a typical C&D waste stream might be different from that of the leachate in this study. For example, in this study one main component omitted was gypsum drywall, because it was not widely used in construction projects until the 1970's. As showed previously, gypsum drywall is one of the larger fractions in current C&D waste streams.

**Table 2-6 Lysimeter Analysis Results**

| <b>Parameters</b>                        | <b>Lysimeter 1<br/>(Masonry Based)</b> | <b>Lysimeter 2<br/>(Wood Based)</b> |
|--|--|-------------------------------------|
| pH                                       | 7.45                                   | 6.9                                 |
| Conductivity ( $\mu\text{m}/\text{cm}$ ) | 2,220                                  | 2,000                               |
| Alkalinity (mg/L as $\text{CaCO}_3$ )    | 70                                     | 350                                 |
| Hardness (mg/L as $\text{CaCO}_3$ )      | 770                                    | 910                                 |
| COD (mg/L)                               | 320                                    | 340                                 |
| Total Carbon (mg/L)                      | 130                                    | 180                                 |
| Lignin-Tannin (mg/L as tannic acid)      | 17                                     | 40                                  |
| Suspended Solids (mg/L)                  | 8                                      | 13                                  |
| Total Residue (mg/L)                     | 2,000                                  | 1,900                               |
| Fixed Residue (mg/L)                     | 1,600                                  | 1,500                               |
| Total Volatile (mg/L)                    | 400                                    | 400                                 |
| Iron (mg/L)                              | 1.6                                    | 16                                  |
| Manganese (mg/L)                         | 6.4                                    | 28                                  |
| Zinc (mg/L)                              | 0.21                                   | 0.61                                |

Source: Ferguson and Male, 1980

#### 2.4.3.2 Thurn Study

Thurn (1997) recently conducted a laboratory lysimeter study on a mixed C&D waste. Components included wood, ferrous metal, drywall, concrete, asphalt roof shingles, insulation, and cardboard. All four leaching lysimeters contained the same material. Deionized water was used as a leaching fluid. Two lysimeters were operated under conditions of constant saturation for 12-day periods, after which they were drained and refilled with deionized water. Saturated conditions was used to simulate the disposal scenario, whereby C&D waste in North Florida is commonly dumped directly into sand

quarries, that have been excavated to the groundwater table. The remaining two lysimeters were operated under unsaturated conditions. One-sixth of the saturated volume of a lysimeter was added to each lysimeter every two days, at which point leachate from the previous water addition was removed for analysis. This resulted in the same volume of water being added to the lysimeters every 12 days. This study was conducted over a 72-day period.

The saturated lysimeters stayed constant at approximately pH 11 throughout the experiment while the pH of the unsaturated lysimeters sharply dropped off from pH 11 to a final pH of 6.8 (day 20 – day 30). At the same time the pH was decreasing, the color of the leachate turned from yellow to clear to gray and finally black. The saturated lysimeter leachate remained a bright yellow for the entire experimental period. Alkalinity in leachate from the saturated lysimeter followed a decreasing leaching pattern, while the alkalinity in the unsaturated lysimeters showed increasing levels. The increasing trend in the unsaturated lysimeters indicated that biological activity was present. Chemical oxygen demand test (COD) and total organic carbon analysis (TOC) exhibited downward trends for both the saturated and unsaturated lysimeters as time progressed. Results for total dissolved solids (TDS) also followed a somewhat downward trend for all lysimeters. Concentrations of sulfate, which was the greatest contributor to TDS, were relatively high as a result of dissolution of gypsum drywall. All of the saturated and unsaturated lysimeters exhibited a fairly constant concentration of the sulfate ions.

The study concluded that there exists a potential for nearby groundwater contamination due to the presence of sulfate, TDS and malodorous hydrogen sulfides.

The leachate in the laboratory lysimeter study provided a baseline for the minimum amount of constituents that will leach from new and clean C&D waste components.

However, several limitations were also observed during the study. First, leachate analysis focused mainly on water quality parameters, such as pH, TDS, COD, and alkalinity. Additional information on metal leaching and hydrogen sulfide generation is still needed, since hydrogen sulfide odor was reported and metal were contained in the waste tested. Second, the leaching solution application rate for the unsaturated lysimeters was fairly high. The experiment simulated a 10-minute duration rainfall amounting to 6.0 in. of precipitation every other day, which is much higher than typical rainfall. Third, since the height of the lysimeter is four feet, leachate produced from the lysimeters only represents the simulation of a 4 ft waste depth.

#### 2.4.4 Summary of Existing and Need Information

In summary, several C&D leachate studies from field-scale landfills have attempted to examine the impacts of the leachate to the environment, especially to groundwater. The studies have identified potential problematic contaminants to groundwater contamination. However, many conclusions heavily rely on survey leachate data obtained from regulatory agencies. No extensive characterization study of field-scale leachate is available with regard to temporal changes and waste decomposition processes occurring within landfills. More leachate data from actual land-disposed C&D waste is necessary in order to assess the characteristics of C&D leachate and its impacts on the surrounding environment. However, difficulties in collecting information on C&D waste landfill leachate exist due to the lack of lined-landfills that accept only C&D waste.

Therefore, laboratory study is essential to assess the true nature of C&D leachate. Although Thurn's laboratory study shed some light on the nature of C&D waste leachate produced from basic C&D waste components, to date, no extensive C&D leachate study in laboratory scale is available. To better characterize the leachate produced by the entire spectrum of C&D waste stream, further laboratory leachate studies should be conducted on C&D waste with varying waste type, waste depth and waste age.

## CHAPTER 3 METHODOLOGY

Two separate leaching column (lysimeter) experiments were performed. The primary objective of leaching lysimeter experiment 1 was to measure the chemical constituents and their concentrations that leached from both individual C&D materials and mixed C&D materials. In leaching lysimeter experiment 2, C&D waste leachate was obtained from laboratory landfill lysimeters, which were built in series to simulate a 20 ft deep landfill, and the leachate was characterized and examined to determine the effects of different waste depths on contaminant leaching and its strength in leachate. A synthetic precipitation leaching procedure (SPLP) test was also conducted to investigate contaminant leachability of C&D materials used in experiment 2. In the following section each experimental methodology is presented and discussed.

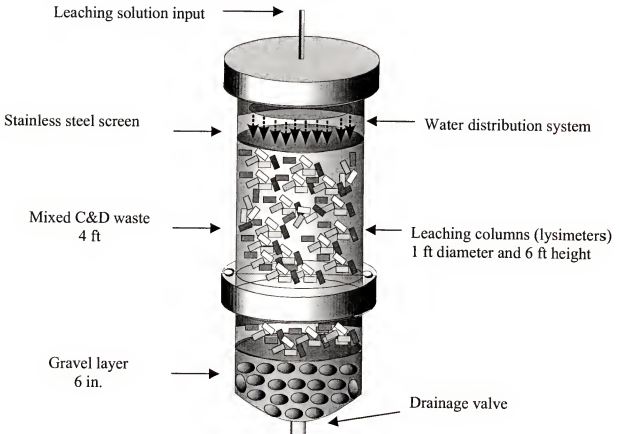
### 3.1. Materials and Methods

Experimental methods included constructing a set of leaching lysimeters (columns), preparing waste materials, and conducting leaching experiments.

#### 3.1.1. Leaching Lysimeters

Leaching lysimeters were constructed of 12-in diameter, schedule 40 polyvinyl chloride (PVC) pipe (Figure 3.1). The height of the lysimeters was 5 ft. A leachate reservoir and drain were constructed with a PVC cap at the bottom of the lysimeters. The drainage cap was filled with a 6 in. washed gravel layer, which was covered by a

stainless steel screen. A stainless steel screen was placed on top of the waste along with a 3.5 in layer of sand. The upper sand layer was included to help establish even water distribution through the waste. The distribution system was constructed inside the top caps. It consisted of spiral wrapped hose with low flow drip sprinkler heads connected every two in. A 2.5 in. headspace on top of the lysimeters was allowed for the water to properly contact the waste.



**Figure 3-1 C&D Waste Leaching Lysimeter**

Before any waste was added to the lysimeters, the system was cleaned. First, the lysimeters and water distribution system were rinsed with deionized water. The gravel layer in the lysimeters was then filled with synthetic precipitation leaching procedure (SPLP) leaching solution. After two days the lysimeters was drained for a final time.

### 3.2. Leaching Lysimeter Experiment I

By measuring the chemical constituents and their concentrations from individual C&D material, a more detailed examination of the leaching processes was presented. All lysimeters were operated under unsaturated conditions. The leaching fluid used was a simulated rainwater, the same as used in the U.S. EPA's SPLP solution (U.S. EPA, 1994). This was performed to better reflect true rainfall conditions. A 3.8-liter leaching solution was added to each lysimeter every two days. Prior to adding the leaching solution, leachate resulting from the previous addition was collected. The experiment was conducted over a 92-day period.

#### 3.2.1. Waste Selection and Preparation

The materials evaluated in the leaching lysimeters included corrugated cardboard, concrete, wood, and drywall (gypsum wallboard). These materials were selected for the leaching experiment because they are considered to be some of the major C&D waste components. Wood (southern pine) and drywall were purchased from a home improvement store. Typical corrugated cardboard from shipping boxes was used as the source of cardboard. The crushed concrete was collected from a local concrete recycling company. The facility collects concrete from demolished structures and processes the



material by crushing and screening. The following table lists the components tested in experiment 1 and the objectives of investigating these waste components.

**Table 3-1 C&D Waste Components and Leaching Experiment Objectives**

| Waste Component | Objectives   |
|-----------------|--|
| Gypsum drywall  | According to the previous studies, sulfate and total dissolved solids are two of the larger constituents in C&D leachate. Gypsum drywall was expected to be a major contributor of these constituents.   |
| Concrete        | Concrete is one of the major waste components in C&D waste stream. This component does affect the leachate pH. Leachate pH may play a significant role in regard to contaminant leaching because of the high buffering capacity of concrete materials. |
| Wood, Cardboard | Wood and cardboard may be a substantial percentage of the C&D waste stream. They are believed to be major contributors of organic compounds such as chemical oxygen demand (COD) and total organic carbon (TOC).                                       |
| Mixed C&D Waste | A mixed waste lysimeter was also used to compare with the characteristics of leachate produced from the individual C&D waste components.   |

In this study, it was necessary to select a standard, uniform size for all materials so that similar surface areas could be achieved and so that the waste components could fit into the lysimeter. A nominal size of two inches was selected for this study. Sheet materials (drywall, cardboard) were cut into 2 in. by 2 in. pieces. Five-cm (2-in.) pieces of clean southern pinewood were cut from 2 in. by 2 in. lumber. The concrete was

collected from a local concrete crushing facility from a stockpile screened to approximately 1 in.

### 3.2.2. Waste Loading

The material weighed for each 1-ft lift was loaded into each lysimeter. After each lift was added to a lysimeter, a tamping device was employed to minimize void space. A thermocouple was then placed into each lysimeter after the second lift was created. This was used to monitor the temperature inside of the waste. An increase or decrease in temperature may be an indicator of chemical or biological reactions taking place within the waste. Table 3-2 presents the characterization of each lysimeter, including bulk density.

**Table 3-2 Summary of Waste Loading**

| <b>Lysimeter</b>                             | <b>1</b>  | <b>2</b> | <b>3</b> | <b>4</b> | <b>5</b> | <b>6</b> |
|--|-----------|----------|----------|----------|----------|----------|
| Waste type                                   | Cardboard | Concrete | Wood     | Drywall  | Drywall  | Mixed    |
| Waste Quantity (lb)                          | 16.5      | 270.5    | 76.0     | 68.0     | 68.0     | 64.0     |
| Waste volume of lysimeter (ft <sup>3</sup> ) | 3.6       | 3.6      | 3.6      | 3.6      | 3.6      | 3.6      |
| Waste density (lb/ft <sup>3</sup> )          | 4.6       | 74.9     | 21.0     | 18.8     | 18.8     | 17.7     |
| Thickness of Top sand layer (in.)            | 3.5       | 3.5      | 3.5      | 3.5      | 3.5      | 3.5      |
| Thickness of bottom sand layer (in.)         | 6.0       | 6.0      | 6.0      | 6.0      | 6.0      | 6.0      |
| Total depth of waste (ft)                    | 4.6       | 4.6      | 4.6      | 4.6      | 4.6      | 4.6      |

### 3.2.3. Leachate Analysis

The volume of collected leachate was measured and recorded. The pH, oxidation-reduction potential (ORP) [Accumet Co. Model 20 ], dissolved oxygen (DO) [YSI Inc. Model 55/12 FT] and specific conductance (HANNA Instruments, Model H19033) were

measured in all leachate samples. A portion of the leachate was then transferred to appropriate containers, preserved and filtered as necessary, and stored at 4°C until analysis. The parameters analyzed and the analytical methods used are summarized in Table 3-3. Redox potential, or oxidation reduction potential (ORP), indicates the oxidizing or reducing capability of a solution, and is controlled by the ratio of oxidants to reductants present. A silver:silver chloride electrode (Accumet 13-620-81) was used for a reference electrode, while oxidation-reduction indicator electrode was a platinum electrode. To implement quality assurance/quality control (QA/QC) practices in the laboratory analysis, blanks, replicates, and calibration check samples were performed as appropriate.

**Table 3-3 Analytical Methods Used for Leachate Analysis**

| Parameter              | Method                              |
|------------------------|-------------------------------------|
| Temperature            | Standard Method 2550 <sup>a</sup>   |
| pH                     | Standard Method 4500-H <sup>+</sup> |
| Total dissolved solids | Standard Method 2540C               |
| ORP                    | Standard Method 2580                |
| Conductivity           | Standard Method 2510                |
| COD                    | Standard Method 5220C               |
| NPOC <sup>b</sup>      | Standard Method 5310B               |
| Anions                 | SW-846 Method 9056 <sup>c</sup>     |
| Cations                | EPA Method 300.7 <sup>d</sup>       |
| Alkalinity             | Standard Method 2320B               |
| Ammonia                | Standard Method 4500-D              |

<sup>a</sup> Source: APHA, 1995

<sup>b</sup> Only non-purgeable organic carbon (NPOC) was measured.

<sup>c</sup> Source: U.S.EPA, 1994

<sup>d</sup> Source: Dionex, 1995

### 3.3. Leaching Lysimeter Experiment 2

The purpose of leaching lysimeter experiment 2 was to simulate a typical C&D waste leachate in a landfill as well as to examine the effect of waste depth on contaminant leaching from simulated leaching lysimeter under unsaturated conditions. Leaching experiment was conducted using a typical composition of C&D waste in the United States. Synthetic rainwater from SPLP test was used as a leaching solution. In experiment 2 additional parameters were measured for the leachate produced from the lysimeters, such as heavy metals, and sulfide. Experiment 2 was conducted over a year period, simulating a 10-year period of C&D landfill operations.

#### 3.3.1. Leaching Lysimeter Set-up

As were used in experiment 1, six leaching lysimeters were used for experiment 2. To simulate a 20-ft waste depth in a landfill a total of five lysimeters were set up in series (Figure 3-2) whereby leachate produced from one lysimeter was pumped into the top of the next lysimeter. The leachate serially flowed through the lysimeters. A single lysimeter, which represents a 4-ft waste depth of a C&D landfill, was also used to compare serial lysimeter leaching. Leaching solution was added to the lysimeters using a low flow rate pump system (MASTERFLEX® L/S™ Model 7419-10 and MASTERFLEX® L/S™ Model 7419-05 ). A flow rate was calculated based on the average rainfall rate in Florida (3 in. per month). Table 3-4 presents application rates of leaching solution in lysimeter experiment 2.

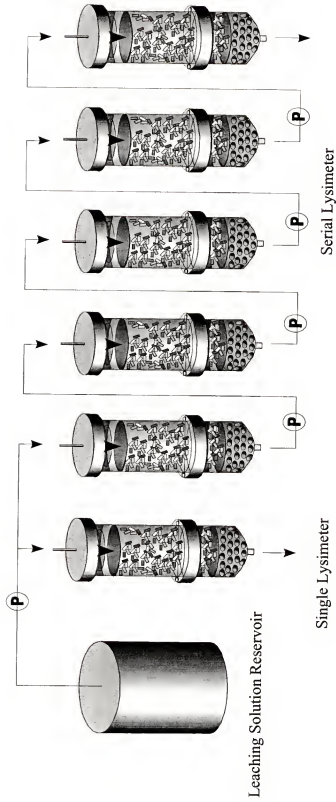


Figure 3-2. C&D Waste Leaching Lysimeter Set-up in Experiment 2

**Table 3-4 Application Rates of Leaching Solution in Lysimeter Experiment 2**

|                   | <b>Pump 1 (Single Lysimeter)</b> | <b>Pump 2 (Serial Lysimeter)</b> |
|-------------------|----------------------------------|----------------------------------|
| Flow Rate         | 46.3 ml/min                      | 30.0 ml/min                      |
| Frequency         | Every 6 hour                     | Every 1 hour                     |
| Duration          | 10 minutes                       | 5 minutes                        |
| Simulation Period | 10 years.                        | 10 years.                        |

### 3.3.2. Waste preparation and Waste Composition

Samples evaluated in the leaching lysimeters were either clean, new construction materials or recycled materials with little chance of contamination from trace chemicals (e.g. paints, adhesives). Because typical demolition waste and mixed C&D waste are so heterogeneous, only C&D materials with known origins and properties were included in this experiment (Table 3-5). A bulky material was size-reduced to a uniform size, nominally to 2 in. by 2 in. pieces, as previously described in the leaching experiment 1.

An average C&D composition was calculated from the EPA report (US EPA, 1998a), which summarized many composition studies from a variety of source. Table 3-5 shows the average waste composition of the waste stream by mass.

### 3.3.3. Waste loading

To ensure a proper mix of the components when loading the C&D materials into the lysimeters, the materials were pre-mixed in a 5-gallon bucket, and then loaded in 1 ft

lifts. After each lift was loaded to the lysimeter, a tamping device was used for waste compaction. In order to monitor the temperature inside the waste in the lysimeter, a thermocouple was placed into each lysimeter after the second lift was created. The average bulk density of the C&D waste in the lysimeters was  $230 \text{ kg/m}^3$  ( $520 \text{ lb/yd}^3$ ). This falls within the range of mixed construction waste density reported in the literature (Tchobanoglous et al., 1993).

**Table 3-5 Sources and Mass Composition of C&D Materials**

| <b>C&amp;D Component</b> | <b>Source</b>  | <b>Mass Composition (%)</b> |
|--------------------------|--|-----------------------------|
| Wood                     | Home Improvement Store, Southern Pine                                    | 33.2                        |
| CCA-Wood                 | Home Improvement Store, Type C, retention value: 0.25 lb/ft <sup>3</sup> | 0.5                         |
| Drywall                  | Home Improvement Store, Gypsum Wallboard Sheet                           | 12.4                        |
| Concrete                 | Concrete Recycling Facility, 1 in. Screened Concrete                     | 29.2                        |
| Copper                   | Home Improvement Store, Copper Wire (1/8 in. dia.)                       | 0.6                         |
| Steel                    | Home Improvement Store, Galvanized Steel Sheet                           | 0.6                         |
| Aluminum                 | Home Improvement Store, Aluminum Sheet                                   | 0.6                         |
| Steel Bar                | Demolition Site, 1 in. dia. Steel Bar                                    | 0.6                         |
| Roofing                  | Home Improvement Store, Roofing Shingles                                 | 13.7                        |
| Insulation               | Home Improvement Store, Fiber Glass                                      | 0.6                         |
| Cardboard                | Construction Site, Corrugated Cardboard                                  | 8.0                         |
| Total                    |  | 100.0                       |

### 3.3.4. Leachate Collection and Analysis

Leachate was drained from a single lysimeter and a serial continuous lysimeter every other day. The volume of collected leachate was measured and recorded. An extensive chemical analysis of the leachate was conducted during the experimental period. Leachate was immediately analyzed for pH, ORP, DO, and specific conductance, as measured in experiment 1. Leachate samples were collected every other day from the single lysimeter and a serial lysimeter for the first month for analysis of conventional water quality parameters and metals. After the first month of sampling, samples were collected every six days for leachate analysis. After a six-month monitoring period, pH, ORP, specific conductance, and dissolved oxygen in leachate were measured once a week until the end of the experiment, while all other parameters were measured once a month.

Conventional water quality parameters employed in leachate analysis were the same as used in the leaching experiment 1 (Table 3-3). In addition, some analytical parameters such as sulfide and metals were also analyzed during the leaching lysimeter experiment 2. Leachate samples for heavy metals required preservation with nitric acid ( $\text{pH} < 2$ ). All samples were stored in a refrigerated room at the University of Florida Solid and Hazardous Waste Laboratory until analyzed.

The analytical methods for the additional parameters are summarized in Table 3-6. U.S. EPA methods (US EPA, 1994) and other standard methods (APHA, 1995) were used when available. Most parameters were selected for their regulatory relevance. Other parameters such as ions and chemical oxygen demand (COD) aided in assessing the overall chemical characteristics and contaminant leaching processes of the leaching



lysimeters. For ion analysis, a Dionex ion chromatography (Dionex DX-500) unit was used following sample filtration (0.45- $\mu$ m membrane filter).

To implement quality assurance/quality control (QA/QC) practices in the laboratory analysis, blanks, duplicates, and calibration check samples were analyzed as appropriate. All sampling equipment and containers were cleaned and prepared according to established procedures (FDEP, 1992).

**Table 3-6 Additional Analytical Methods Used for Lysimeter Experiment 2**

| Parameter | Method                 |
|-----------|------------------------|
| Sulfide   | Standard Method 4500-D |
| Arsenic   | EPA SW846-7060A        |
| Chromium  | EPA SW846-7191         |
| Copper    | EPA SW846-7211         |
| Iron      | EPA SW846-7280         |
| Manganese | EPA SW846-7461         |
| Zinc      | EPA SW846-7950         |

### 3.4. Synthetic Precipitation Leaching Procedure Batch Test for C&D materials

A synthetic precipitation leaching procedure (SPLP) test was performed (US EPA SW 846-1312) to evaluate contaminant leachability of C&D materials (11 components). The SPLP test simulates a mildly acidic rain. A 100-gram sample was placed in a 2-liter polyethylene container. The SPLP utilizes a slightly acidic solution ( $\text{pH} = 4.20 \pm 0.05$ ) designed to simulate acidic rainwater by adding the 60/40 weight percent mixture of sulfuric and nitric acids without buffer systems. Two liters of SPLP solution were then

added to the container. The container was placed in a rotary extractor and rotated for 18 hours  $\pm$  2 hours at 30 rpm. After tumbling, the mixture was filtered using a pressurized filtration apparatus with a 0.7- $\mu$ m glass fiber filter. The test method was the same as other standardized batch leaching tests such as the Toxicity Characteristic Leaching Procedure with the exception of the leaching fluid. After filtration, leachate was analyzed for a number of chemical constituents (water quality conventional parameters and metals) selected for comparison with the results from the leaching lysimeter experiment.

## CHAPTER 4 RESULTS

### 4.1. Lysimeter Experiment 1

The leachate samples collected from the lysimeters (or leaching columns) in experiment 1 were analyzed for a number of conventional water quality parameters. Five of the lysimeters were filled with single waste components. Materials included in this experiment were cardboard, concrete, wood, and drywall. The sixth lysimeter consisted of a mixture of all four of these waste components by equal volume (i.e. 25 %). In this section the major results from the analyses are presented as a function of time.

#### 4.1.1. Leachate Generation

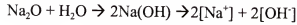
Approximately 3.7 liters (1 gal.) of the synthetic precipitation leaching procedure (SPLP) leaching solution were added to each lysimeter every two days. Leachate resulting from the previous addition was collected prior to the addition of the fresh leaching solution. The leachate volume collected at each draining was constant at approximately 3.7 liters throughout the experiment. The time at which the volume collected became constant ranged from day 5 to day 20, depending on the lysimeter. The average total volume of leachate generated from the lysimeters was 163 liters (43 gal.) over a 92-day experimental period. Appendix A contains leachate volume data for each lysimeter.

#### 4.1.2. Physical Characteristics

The leachate produced from the cardboard and wood lysimeters maintained a light yellow color throughout the experiment as a result of organic acid formation as well as high molecular weight compounds (lignin-tannic acids) from the dissolution and decomposition of organic matter into percolating liquids. A strong pine wood smell was observed in the wood lysimeter, while no distinguishing characteristics were observed in the concrete lysimeter. The drywall lysimeter and the mixed waste lysimeter possessed a strong odor, indicating that sulfate ions from gypsum drywall were reduced to sulfides by sulfate-reducing bacteria.

#### 4.1.3. pH, Dissolved Oxygen, Oxidation Reduction Potential Measurements

The pH of the lysimeters from Experiment 1 is presented in Figure 4-1. The concrete-only lysimeter resulted in the highest pH levels, with measurements consistently above 11. Concrete is a mixture of aggregate (e.g., sand, gravel), cement, and water. Concrete aggregates in Florida are supplied primarily from crushed limestone ( $\text{CaCO}_3$ ) and sand (Graves, 1991). Alkali oxides ( $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) comprise less than 1% (by mass) of cement, while CaO content in cement is typically 20% (by mass) (Glasser et al., 1987). It is well known that the release of hydroxyl ions from the dissolution of the alkali hydroxides [ $\text{K}(\text{OH})$ ,  $\text{Na}(\text{OH})$ ] and calcium hydroxide [ $\text{Ca}(\text{OH})_2$ ] causes the pH of water to rise to basic levels (pH 11 to 13) (Glasser et al., 1987; Mather, 1999; Sagüés et al., 1997; Li et al., 1999). The dissolution processes of calcium, potassium, and sodium can be written as follows:



Therefore, the high pH from the concrete lysimeter leachate was believed to be a result of the dissolution of the alkali hydroxides and calcium hydroxide  $[\text{Ca(OH)}_2]$ .

The mixed C&D waste lysimeter resulted in a final pH near neutral. Cardboard and wood remained acidic throughout the experiment (pH 4.5 and pH 4.4, respectively). These acidic pH values were believed to result from both the dissolution of high molecular weight compounds (e.g. organic acids, lignin and tannic acids) and the SPLP leaching solution (i.e. pH 4.2).

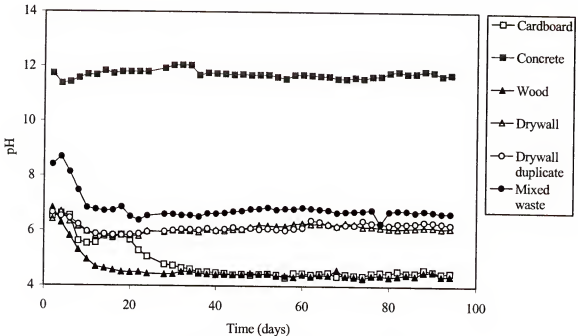


Figure 4-1 pH Results in Experiment 1

With an exception of the concrete-only lysimeter, dissolved oxygen from all other C&D component lysimeters (cardboard, wood, drywall) rapidly decreased over time and remained constant at below 1 mg/L (Figure 4-2). The dissolved oxygen (DO) concentrations of leachate from the concrete-only lysimeter remained in the range of 7 to 8 mg/L.

The results of oxidation-reduction potential (ORP) measurements are shown in Figure 4-3. All of the lysimeters exhibited a decreasing trend of ORP, which indicated that many of the constituents in the leachate produced from the lysimeters existed in reduced forms. The mixed waste resulted in the lowest ORP measurement. It reflects the most reduced condition occurring in the leachate. Oxidation-reduction potential (ORP) measurements in the mixed waste leachate dropped dramatically over time (30 days) and remained between -260 mV and -370 mV throughout the experiment. Since biologically active environments often create reducing conditions (Stanier et al., 1986; Black, 1992), it indicates that biological activity probably occurred within the mixed lysimeter and created the reducing conditions. Many of the results presented in this chapter support the hypothesis that biological activity occurred in a number of the lysimeters. Supporting evidence for this hypothesis will be summarized in Chapter 5.

#### 4.1.4. Dissolved Solids

Figure 4-4 shows the results of total dissolved solid (TDS) concentrations measured in the leachate. The drywall lysimeters exhibited the highest TDS concentrations and the mixed C&D waste lysimeter (25% drywall by volume) was next highest.

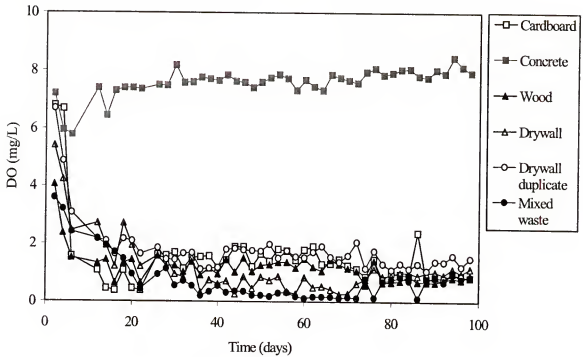


Figure 4-2 DO Measurements in Experiment 1

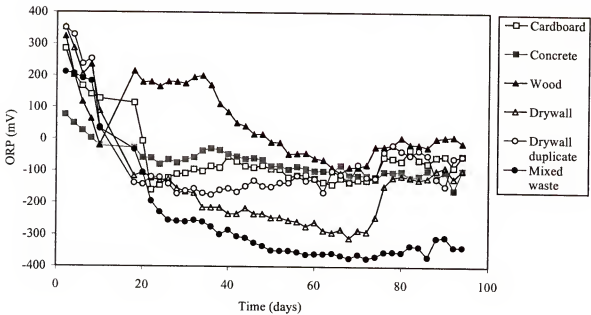
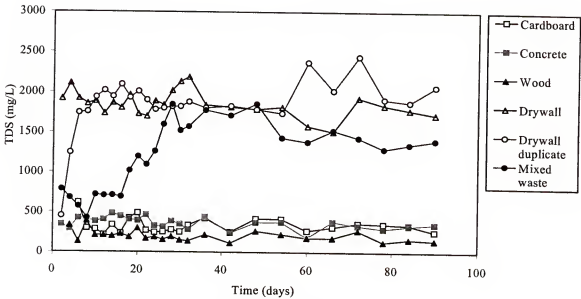


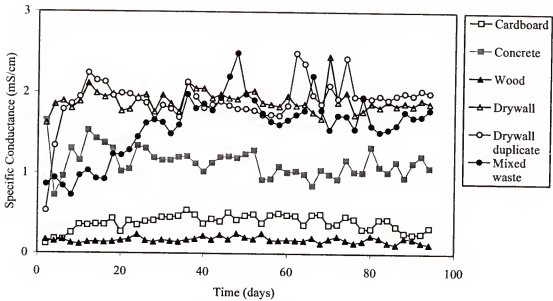
Figure 4-3 ORP Measurements in Experiment 1



**Figure 4-4 TDS Results in Experiment 1**

The results of total dissolved solid concentrations show gypsum drywall to be the greatest contributor of dissolved solids. Specific conductance is a frequently used indicator of dissolved solids content. Specific conductance measures the ability of a solution to carry an electrical current. The results of specific conductance are shown in Figure 4-5. The specific conductance in all drywall and mixed waste lysimeters was high compared to the others (cardboard and wood). The concrete-only lysimeter showed elevated levels of specific conductance in the leachate as a result of alkalinity (hydroxyl ions, carbonate ions, and bicarbonate ions) and some cations, such as calcium, potassium and sodium.





**Figure 4-5 Specific Conductance Results in Experiment 1**

#### 4.1.5. Organic Constituents

Organic matter in leachate is measured commonly by chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total organic carbon (TOC). The BOD measures the oxygen depletion within a sample due to biological activity, whereas the COD uses a strong chemical oxidant to oxidize organic matter in leachate. The TOC is determined by measuring the amount of organic carbon in leachate regardless of the carbon's oxidation state. In this study, leachate was analyzed for COD and TOC. Non-purgeable organic carbon (NPOC) was measured in the leachate for TOC since it was considered that the purgeable organic carbon present in the C&D leachate was negligible compared to the non-purgeable. The results of chemical oxygen demand (COD) and organic carbon [non-purgeable organic carbon (NPOC)] are shown in Figures 4-6 and 4-7, respectively.

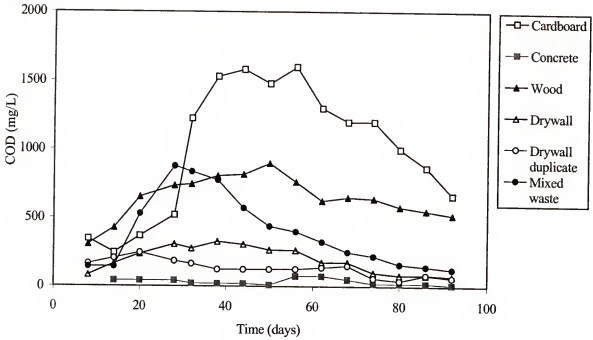


Figure 4-6 COD Results in Experiment 1

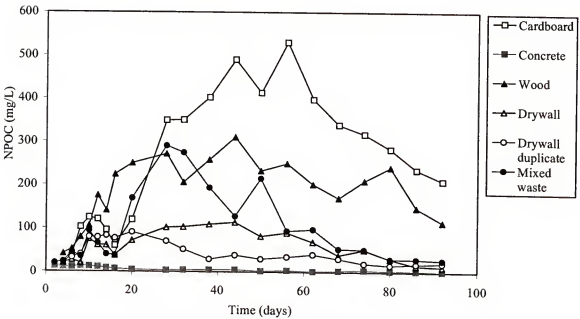
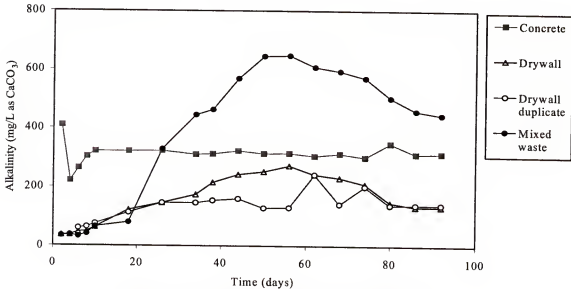


Figure 4-7 NPOC Results in Experiment 1

The COD and NPOC from cardboard, wood, and mixed waste lysimeters exhibited an increasing pattern initially and then followed a downward trend as time progressed. The greatest contributor to the organic carbon concentration was cardboard, followed by wood. The results show the lowest concentration of organics in the leachate to be from the drywall and concrete lysimeters.

#### 4.1.6. Alkalinity and Ammonia

The results of alkalinity are shown in Figure 4-8. Alkalinity in the mixed waste lysimeter demonstrated initially an increasing trend, followed by a decrease after reaching a maximum at 50 days.



**Figure 4-8 Alkalinity Results in Experiment 1**

Alkalinity from the concrete-only lysimeter stayed constant throughout the experimental period probably due to the release of hydroxyl ions from alkali hydroxides [K(OH), Na(OH)] and calcium hydroxide as well as the dissolution of calcium carbonate from concrete. No ammonia was detected above the detection limit of 0.5 mg/L in the leachate from all lysimeters throughout the experiment.

#### 4.1.7. Anions

Anions evaluated for this study included fluoride, chloride, nitrate, nitrite, bromide, phosphate, and sulfate. No fluoride, nitrate, nitrite, bromide, or phosphate were detected in any leachate samples. The results of sulfate and chloride are presented in Figures 4-9 and 4-10, respectively. The highest concentration of sulfate was observed in the drywall lysimeter. The sulfate concentrations remained relatively constant throughout the experiment, ranging from 538 mg/L to 1255 mg/L. The average sulfate concentration from both drywall lysimeters was 938 mg/L. The sulfate concentrations from the mixed waste lysimeter also remained relatively constant with an average of 448 mg/L. The sulfate concentrations of both lysimeters exceeded the secondary drinking water standard of 250 mg/L for sulfate (CFR, 1997).

Chloride, which is a typical indicator parameter of municipal solid waste leachate, was present in only small amounts in the leachate, as shown in 4-10. The highest concentration of chloride was observed in the drywall lysimeter. Chloride from this lysimeter dramatically reached a peak and then followed a slight downward trend. The concentration ranges of chloride were from 9.2 mg/L to 26.4 mg/L. Chloride concentrations from all other lysimeters remained relatively constant throughout the experiment.

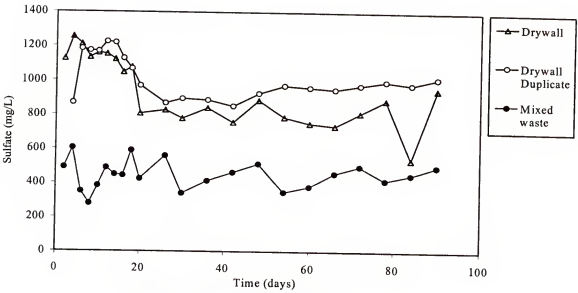


Figure 4-9 Sulfate Results in Experiment 1

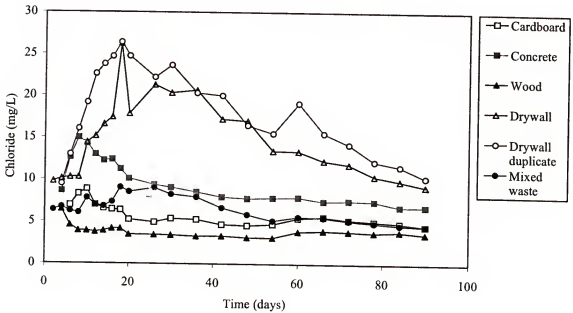


Figure 4-10 Chloride Results in Experiment 1

#### 4.1.8. Cations

The cations analyzed consisted of ammonium, calcium, magnesium, potassium, and sodium. The results of the cations are shown in Figure 4-11 through Figure 4-14. No ammonium was detected in the leachate. Calcium was the predominant cation observed in the leachate in both the drywall lysimeter and the mixed waste lysimeter. The highest concentration of calcium was observed in the drywall lysimeter (Figure 4-11). The concentration of calcium in the leachate from the mixed waste lysimeter showed an increasing pattern up to day 30 and then stayed constant for the rest of the experimental period. The leaching trend for calcium closely resembled the sulfate leaching pattern, again indicating the dissolution of gypsum drywall. The concentration of calcium in the mixed waste lysimeter approached that in drywall lysimeters more closely than sulfate because calcium also was being leached from the concrete. The average concentrations of the drywall lysimeter and the mixed lysimeter were 437 mg/L and 268 mg/L, respectively.

The highest concentration of magnesium was observed in the mixed waste lysimeter (Figure 4-12). The magnesium concentrations increased for the first month and then stayed constant at approximately 25 mg/L. However, magnesium concentrations from all other lysimeters remained fairly low throughout the experiment.

Figure 4-13 displays the potassium concentrations analyzed in the leachate. The potassium concentrations from the mixed waste lysimeter and the concrete lysimeter increased dramatically up to day 20 and then declined slowly for the rest of the experimental period.

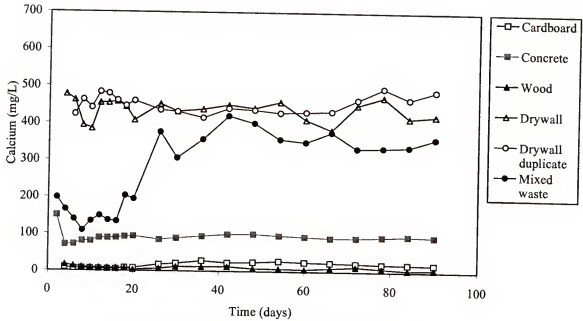


Figure 4-11 Calcium Results in Experiment 1

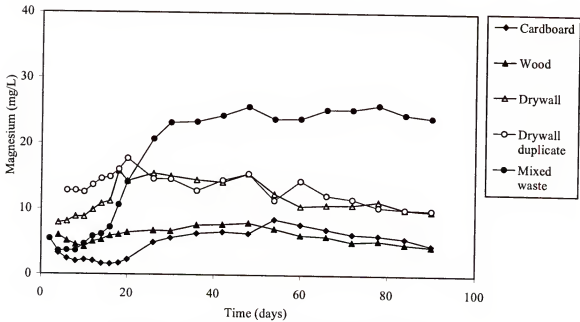
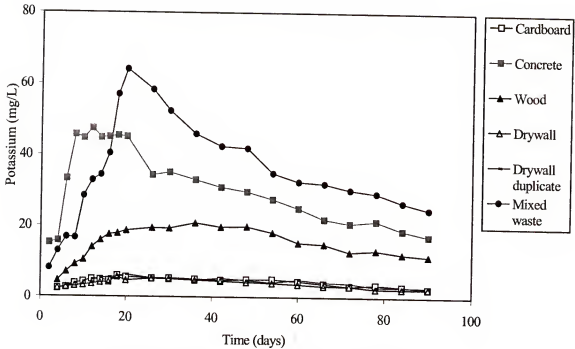


Figure 4-12 Magnesium Results in Experiment 1

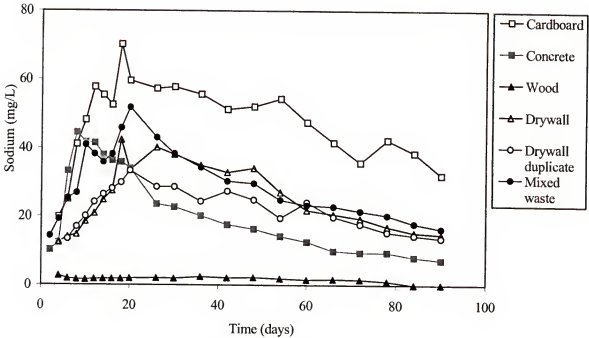


**Figure 4-13 Potassium Results in Experiment 1**

The average potassium concentrations of the mixed C&D waste lysimeter and the concrete-only lysimeter were 34.7 mg/L and 31.8 mg/L, respectively. Potassium concentrations from the wood lysimeter stayed constant with an average of 14.9 mg/L. The drywall and cardboard lysimeters leached less potassium relative to the other lysimeters.

Sodium is very commonly found in municipal solid waste leachate. The highest concentration of sodium was observed in the leachate from the cardboard lysimeter (Figure 4-14). The sodium concentration started off at a high level and then followed a slight downward trend. All other lysimeters displayed the similar trends with the exception of the wood lysimeter. The sodium concentration from the wood lysimeter was significantly lower than others.





**Figure 4-14 Sodium Results in Experiment 1**

#### 4.1.9. Solid and Ion Balance

Solids and ion balances were performed to check analytical accuracy as well as to evaluate the composition of ions in leachate. The solids balance analysis involved comparing the sum of the total dissolved solid (TDS) measurements to the sum of the ions leached were compared. The TDS concentrations from the lysimeter were summed by mass. Next, the results of ions for the lysimeter were summed. In order to obtain the total mass of TDS and ions, leachate concentrations of TDS and ions were multiplied by the volume collected for each sample. Finally, the ratio of the mass of ions to the mass of TDS was calculated. The results for the solid balance of lysimeter experiment 1 are presented in Table 4-1.

The results of the solids balance for the drywall lysimeter and the mixed waste lysimeter displayed relatively good agreement between TDS measurements and the measured ions leached for the entire experimental period (80.2% and 81.4 %, respectively). In other words, approximately 80 % of TDS in both lysimeter leachates comprised the ionic species listed in Table 4.1. In the concrete-only lysimeter, alkalinity and calcium were the major contributors to the dissolved solids. A high percentage of the mass ratio between total ions leached and total TDS measured was observed. For the mixed C&D waste lysimeter, most of solids consisted of sulfate, calcium, and alkalinity. The remaining inorganic ions such as chloride, sodium, and potassium leached only in small amounts from all lysimeters.

**Table 4-1 Solid Balance in Experiment 1**

**unit: mg**

| <b>Ions</b>           |            | <b>Cardboard</b> | <b>Concrete</b> | <b>Wood</b>   | <b>Drywall</b> | <b>Mixed</b>   |
|-----------------------|------------|------------------|-----------------|---------------|----------------|----------------|
| <b>Anion</b>          | Sulfate    | 920              | 1,710           | 630           | 142,230        | 73,350         |
|                       | Chloride   | 880              | 1,430           | 550           | 2,530          | 1,020          |
|                       | Alkalinity | 2,230            | 33,630          | 200           | 15,840         | 43,970         |
| <b>Cation</b>         | Calcium    | 5,140            | 16,930          | 3,130         | 71,700         | 53,290         |
|                       | Potassium  | 730              | 5,190           | 2,450         | 720            | 6,200          |
|                       | Magnesium  | 910              | 20              | 940           | 2,010          | 3,480          |
|                       | Sodium     | 8,100            | 3,280           | 240           | 3,850          | 4,730          |
| <b>Total (mg)</b>     |            | <b>18,910</b>    | <b>62,190</b>   | <b>8,140</b>  | <b>238,880</b> | <b>186,040</b> |
| <b>TDS total (mg)</b> |            | <b>54,720</b>    | <b>59,640</b>   | <b>29,240</b> | <b>297,780</b> | <b>228,430</b> |
| <b>% Ions / TDS</b>   |            | <b>34.6%</b>     | <b>104.3%</b>   | <b>27.8%</b>  | <b>80.2%</b>   | <b>81.4%</b>   |

The cumulative mass of TDS leached from the cardboard and wood waste lysimeters was much greater than the amount of inorganic ions leached (dissolved inorganic ions accounted for approximately 30% of the TDS). A probable explanation for this was that dissolved organic constituents from the cardboard and wood comprised a

large amount of the solids leached. The dissolved organic compounds (e.g. organic acids) contributed a measurable amount of the dissolved solids content. After drying the TDS samples, a yellow-brown crust ringed the crucible; this was likely dissolved organic matter.

An ion balance analysis was conducted for the lysimeters with major C&D waste components to determine the composition of ionic species in the leachate and to check electrical neutrality for quality assurance. If significant differences in a cation-anion balance exist, it can be assumed that an error was made in the analysis of the individual constituents or that one or more ionic species were neglected in the analysis.

The ion balance results for concrete, drywall and mixed waste lysimeters matched well, with less than a 10% difference (Table 4-2). Calcium and sulfate were the predominant ions in the leachate from the drywall and mixed C&D waste lysimeters. Alkalinity, which resulted from biological activity as well as concrete, was one of the major inorganic constituents in the mixed waste lysimeter.

**Table 4-2 Ion Balance in Experiment 1** **unit: meq**

| Ions                      |             | Cardboard | Concrete | Wood  | Drywall | Mixed |
|---------------------------|-------------|-----------|----------|-------|---------|-------|
| Anion                     | Sulfate     | 19        | 36       | 13    | 2,960   | 1,530 |
|                           | Chloride    | 25        | 40       | 16    | 71      | 29    |
|                           | Alkalinity  | 61        | 919      | 5     | 430     | 1,200 |
|                           | Total (meq) | 105       | 995      | 34    | 3,460   | 2,760 |
| Cation                    | Calcium     | 256       | 845      | 156   | 3,580   | 2,660 |
|                           | Potassium   | 19        | 133      | 63    | 18      | 158   |
|                           | Magnesium   | 75        | 2        | 77    | 165     | 287   |
|                           | Sodium      | 352       | 142      | 11    | 167     | 206   |
|                           | Total (meq) | 702       | 1,120    | 306   | 3,930   | 3,310 |
| % Difference <sup>a</sup> |             | 74.0%     | 6.0%     | 79.9% | 6.2%    | 9.1%  |

a.  $(\text{total meq of cation} - \text{total meq of anion}) / (\text{total meq of cation} + \text{total meq of anion}) * 100$

Cardboard and wood leached ionic species in considerably lower quantities in comparison with the drywall-containing lysimeters. Also, the equivalent contribution from cations was much greater than that of anions in the cardboard and wood waste lysimeters. Organic acids likely accounted for the remaining anions. This follows the same rationale as presented in solid balance analysis.

Calcium and alkalinity were the predominant ionic species in the concrete-only lysimeter leachate. The leaching of those ions might have occurred by the dissolution of the alkali hydroxides and calcium hydroxide, as described previously. Minor amounts of chloride, potassium, sodium, and magnesium were measured in some lysimeters.

#### 4.1.10. Quality Assurance and Quality Control

To implement quality assurance/quality control (QA/QC) practices in leachate analysis, laboratory blanks, duplicates, and calibration check samples were performed as appropriate. Appendix C includes QA/QC data during the leachate analysis.

In experiment 1, a drywall duplicate lysimeter was used to serve as a quality control check. In order to determine differences between the drywall lysimeters (drywall, drywall duplicate), a statistical analysis (a General Linear Model with Repeated Measures) was performed. The Proc Mixed Procedure in SAS was used to conduct the analysis. No statistical differences of most parameters, such as pH, total dissolved solids, sulfate, and chloride, were observed between the lysimeter leachates ( $p\text{-value} > 0.05$ ). However, chemical oxygen demand (COD) and non-purgeable organic carbon (NPOC) concentrations in the drywall duplicate lysimeter were significantly lower than the drywall lysimeter ( $p\text{-value} < 0.05$ ).

Since COD and NPOC (i.e. organic acids, lignin and tannin) can be produced from the byproducts of biological reactions as well as the dissolution of organic matter into percolating liquids, the degree of biological activity and dissolution process were somewhat different between the lysimeters.

#### 4.2. Lysimeter Experiment 2

The results from lysimeter experiment 2 show the effect of waste depth (single vs. serial) on the leachate composition. The lysimeters contained a typical composition of mixed C&D waste (by mass) in the U.S. A single lysimeter represented a 4-ft depth of waste contained in a C&D waste landfill. On the other hand, the serial lysimeter, which consisted of five lysimeters, simulated a 20-ft waste depth of a C&D waste landfill. In this section, the results of leachate chemical analyses from both the single lysimeter and the serial lysimeter are presented as a function of time.

##### 4.2.1. Leachate Generation

The leachate volume collected from the single lysimeter was constant after day 15 at approximately 3.5 liters throughout the experiment. The leachate volume collected from the serial lysimeter became constant at 3.3 liters after day 100 because it took much more time to bring wastes to field capacity than the single lysimeter. The total volume of leachate produced from the single lysimeter was approximately 624 liters (165 gallons) over a 365-day experimental period, while the leachate volume drained from the serial lysimeter was 535 liters (141 gallons). Appendix B contains leachate volume data of both sets of the lysimeters.

#### 4.2.2. Physical Characteristics and Hydraulic Properties of Lysimeters

The dimensions, physical characteristics and hydraulic properties of the lysimeters are shown in Table 4-3. Waste volume ( $V_w$ ) was estimated using the total waste mass and specific gravity of each waste component. More detailed information regarding the method used to estimate the waste volume is provided in Appendix D.

Adsorbed water volume ( $V_c$ ) was obtained from the total volume of water that was required to bring the waste to field capacity (defined as the maximum moisture that porous media can hold against gravity in solid waste). The volume was determined from the volume of leaching solution added before leachate production occurred. Since the waste materials were dry, it was assumed that minimal water existed within the materials. Void (or air) volume ( $V_a$ ) was estimated by subtracting the waste volume ( $V_w$ ) and the volume of adsorbed water ( $V_c$ ) from the total lysimeter volume ( $V_l$ ). A void volume of 0.35 (by volume percentage) was obtained for both sets of the lysimeters.

Field capacity was 0.13 and 0.15 for the single lysimeter and serial lysimeter (by volumetric percent), respectively. To date, no field capacity data for C&D waste is available from the literature. These values are less than the ranges of field capacity for municipal solid wastes (30 to 40 volumetric percent) reported in the literature (Coline et al., 1991; Zeiss and Major, 1993; Bengtsson et al., 1994). This is because municipal solid wastes (e.g. paper, textile, food waste, etc) have more moisture holding capacity than C&D wastes. Water residence time, which is defined as the time it requires to flow one pore volume of residence water, was measured to be 6 days for the single lysimeter and 34 days for the serial lysimeter by the volume of adsorbed water ( $V_c$ ) divided by flow rate ( $Q$ ). This also assumed that all water is mobile.

**Table 4-3 Physical characteristics and Hydraulic Properties of Lysimeters in Experiment 2**

| Properties  | Single                             | Serial                             |
|---|------------------------------------|------------------------------------|
| Leachate Volume Generated<br>(cm of water / kg C&D waste) | 31                                 | 5.3                                |
| Lysimeter Volume ( $V_l$ )                                | 3 ft <sup>3</sup> (22.5 gallons)   | 15 ft <sup>3</sup> (112.5 gallons) |
| Waste Volume ( $V_s$ )                                    | 1.5 ft <sup>3</sup> (11.3 gallons) | 7.5 ft <sup>3</sup> (56.3 gallons) |
| Lysimeter Area (A)  | 0.75 ft <sup>2</sup>               | 0.75 ft <sup>2</sup>               |
| Waste Height (H)  | 4 ft                               | 4 ft                               |
| Adsorbed Water plus Capillary Water<br>( $V_c$ )          | 0.4 ft <sup>3</sup> (3.0 gallons)  | 2.3 ft <sup>3</sup> (17 gallons)   |
| Air or Void ( $V_a$ )                                     | 1.1 ft <sup>3</sup> (8.2 gallons)  | 5.2 ft <sup>3</sup> (39.2 gallons) |
| Pore Volume ( $V_p$ )                                     | 1.5 ft <sup>3</sup> (11.2 gallons) | 7.5 ft <sup>3</sup> (56.2 gallons) |
| Number of Pore Volumes Eluted                             | 15.0                               | 2.8                                |
| Field Capacity ( $V_c/V_l$ )                              | 0.13                               | 0.15                               |
| Porosity ( $V_p/V_l$ )                                    | 0.5                                | 0.5                                |
| Saturation ( $V_w/V_p$ )                                  | 0.27                               | 0.30                               |
| Residence Time of Water <sup>a</sup>                      | 6 days                             | 34 days                            |

<sup>a</sup> Assumes all water is mobile.

#### 4.2.3. Conventional Parameters

The conventional water quality parameters included are pH, dissolved oxygen (DO), oxidation reduction potential (ORP), specific conductance, total dissolved solid (TDS), alkalinity, and hydrogen sulfide.

The pH of the lysimeters is presented in Figure 4-15. The pH of the single lysimeter ranged from 5.9 to 7.1 with an average of 6.5. The pH dropped dramatically to approximately 6 for the first month and then increased to neutral conditions (pH 6.5 to 7), whereas the pH of the serial lysimeter remained constant in the range of 6.5 to 7.0. The average pH of the serial lysimeter was 6.7, which was slightly higher than the single lysimeter pH.

The dissolved oxygen concentrations in leachate from both the single lysimeter and the serial lysimeter dropped rapidly over time and remained constant at below 2 mg/L (Figure 4-16). The measurements of oxidation reduction potential in the leachate, both from the single lysimeter and the serial lysimeter, followed a trend similar to dissolved oxygen. It dropped dramatically over time (day 50) and remained between –270 and –380 mV throughout the experiment (Figure 4-17). This indicated that many constituents of the leachate produced in the lysimeters existed in reduced forms. In landfill leachate, highly reduced conditions are typically found as a result of the anaerobic microbial activity, with values usually less than –200 mV (Ham and Booker, 1982). It was believed to be a result of biological activity (specifically by sulfate reducing bacteria) that occurred within the lysimeters. Again, supporting evidence for the occurrence of biological activity is presented in section 5.2 in Chapter 5.

Figure 4-18 presents the results of specific conductance measurements. Specific conductance from the single lysimeter and the serial lysimeter increased for the first two months and then remained relatively constant through the remainder of the experiment.



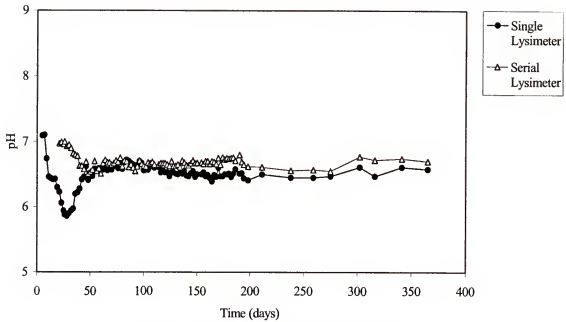


Figure 4-15 pH Results in Experiment 2

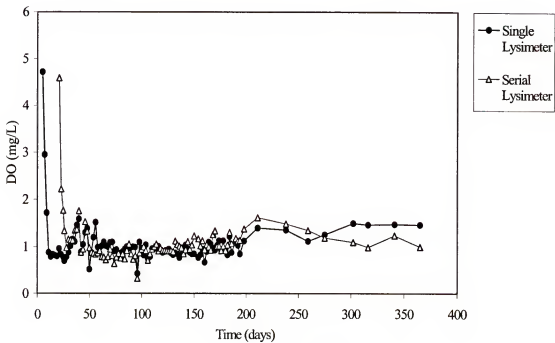


Figure 4-16 DO Results in Experiment 2

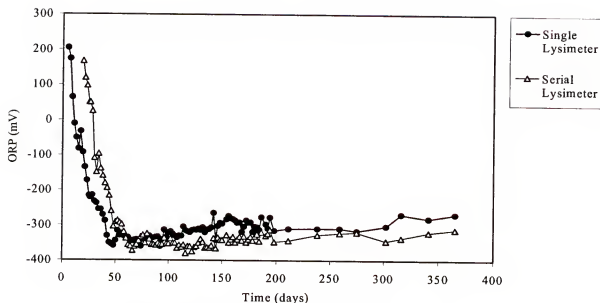


Figure 4-17 ORP Results in Experiment 2

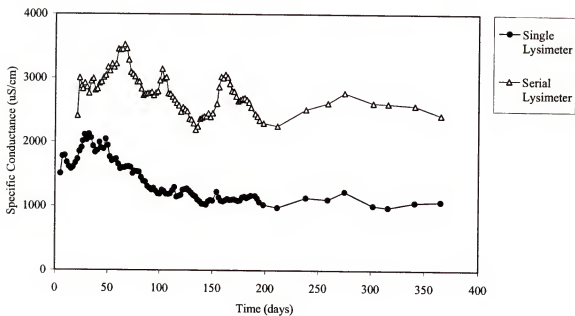


Figure 4-18 Specific Conductance Results in Experiment 2

The average of specific conductance measurement from the single lysimeter and the serial lysimeter was 1.4 mS/cm and 2.8 mS/cm, respectively. The specific conductance from the serial lysimeter was consistently much higher than that of the single lysimeter, indicating that the leachate characteristics are dependent on the depth of waste. Increased depths resulted in more dissolved solids in leachate (or percolate), as the contact time between the solid and liquid phases increased.

Like specific conductance, the total dissolved solid (TDS) content was greater in the serial lysimeter due to a greater waste depth (Figure 4-19). The TDS concentration decreased slightly for the first five months and then stayed relatively constant through the remainder of the experiment. The single lysimeter showed a decreasing leaching pattern as a function of time and then remained fairly constant. The average TDS concentrations both from the serial lysimeter and the single lysimeter were 2,300 mg/L and 1,204 mg/L, respectively. These concentrations exceeded the secondary drinking water standard of 500 mg/L for TDS.

Alkalinity measures the leachate's buffering capacity based on its ability to neutralize acids. In landfill leachate, this pH buffering capacity is primarily as a result of carbonate-bicarbonate species and hydroxides. Since waste degradation proceeds through stages of organic acid and carbon dioxide production, the concentrations of these constituents are dependent primarily on the degree of biological activity in the waste. Figure 4-20 presents the results of alkalinity in the leachate.

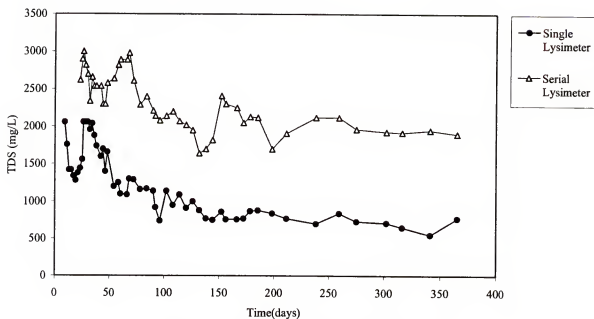


Figure 4-19 TDS Results in Experiment 2

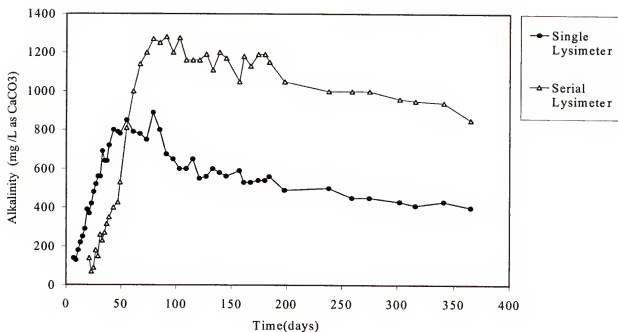


Figure 4-20 Alkalinity Results in Experiment 2

Alkalinity in the serial lysimeter dramatically increased over time (approximately up to 80 days) and then followed a gradual decrease. A similar trend was also observed in the single lysimeter. However, the alkalinity concentration in the serial lysimeter was much higher than that of the single lysimeter.

The results of total sulfide ( $\text{mg/L as S}^{2-}$ ) concentrations are presented in Figure 4-21. Sulfate resulting from the dissolution of gypsum drywall was reduced to sulfides by sulfate reducing bacteria (SRB). This sulfate reduction to sulfide is more discussed in more detail in Chapter 5. Sulfides in the serial lysimeter leachate were not detected for the first month during which the anaerobic and sulfate reducing conditions were not yet established. Thereafter, the concentration of sulfides increased considerably over time (day 150) and then followed a slow decreasing trend (day 200), after which they remained constantly in the range of 15 to 25  $\text{mg/L}$ .

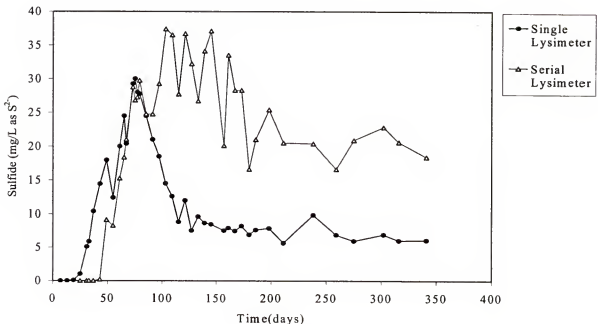


Figure 4-21 Total Sulfide Results in Experiment 2

Although the sulfide concentration trend in the single lysimeter was quite similar to the one in the serial lysimeter, consistently lower concentrations of sulfides in the leachate were observed with the exception of the initial leaching period (approximately up to day 70).

#### 4.2.4. Organic Constituents

Figure 4-22 displays the non-purgeable organic carbon measured in the lysimeter leachate. The concentration of organic carbon in the serial lysimeter began at a high level, sharply decreased from 630 mg/L to less than 50 mg/L in six months, and then remained constant in the range of 20 to 32 mg/L thereafter. The leaching trend and concentration range of the single lysimeter were not dramatically different from those of the serial lysimeter.

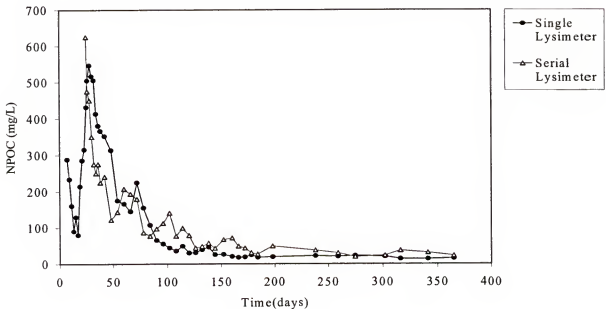
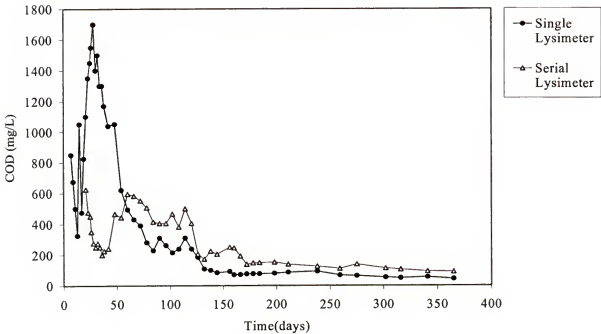


Figure 4-22 NPOC Results in Experiment 2

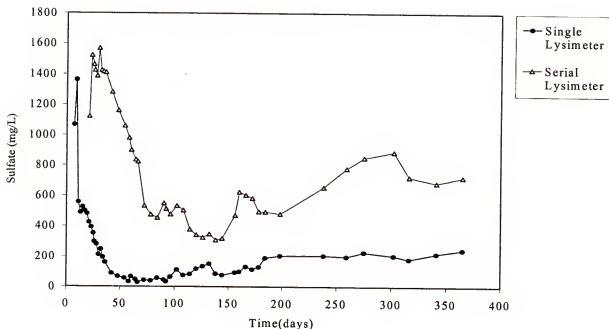
Figure 4-23 shows the results of COD measurements in the leachate. The COD leaching trend of the single lysimeter was very similar to the NPOC trend. The concentration range was from 44 mg/L to 1700 mg/L. However, the concentrations of COD in the serial lysimeter fluctuated over time for the first six months and then remained relatively constant at an average of approximately 120 mg/L. The COD leaching trend did not follow the NPOC leaching trend.



**Figure 4-23 COD Results in Experiment 2**

#### 4.2.5. Anions

Anions measured in the leachate included chloride, sulfate, nitrate, fluoride, nitrite, and bromide. No fluoride, nitrite, nitrate, or bromide was detected in any of the leachate samples. Figure 4-24 illustrates the sulfate concentrations measured in the leachate.



**Figure 4-24 Sulfate Results in Experiment 2**

Sulfate concentrations in the single lysimeter began at a high level, and then rapidly decreased from 1,350 mg/L to approximately 100 mg/L at day 50. The sulfate concentrations in the leachate increased slightly from less than 100 mg/L to approximately 200 mg/L by day 200, after which they remained nearly constant. The average sulfate concentration of the single lysimeter was 225 mg/L. The sulfate in the leachate produced from the serial lysimeter followed a leaching trend similar to the single lysimeter but exhibited much higher concentrations. Sulfate concentrations decreased from 1,570 mg/L to 350 mg/L by day 150, increased to 790 mg/L, and then remained between 890 mg/L to 720 mg/L. The average concentration of the serial lysimeter was 794 mg/L.



The results of chloride concentrations are presented in Figure 4-25. The chloride leaching trend exhibited by the single lysimeter was similar to that of the serial lysimeter but displayed much lower concentrations throughout the experiment. Chloride concentrations in the single lysimeter decreased dramatically from 27.3 mg/L to 4.5 by day 100 and then remained relatively constant in the range of 1.7 mg/L to 4.6 mg/L. The leachate chloride concentrations in the serial lysimeter decreased continually from 28.7 mg/L to 5.1 mg/L over the 365-day experimental period. The average concentrations from both the single lysimeter and the serial lysimeter were 8.9 mg/L and 16.2 mg/L, respectively.

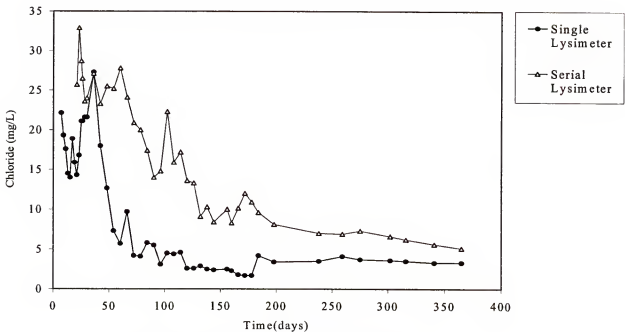


Figure 4-25 Chloride Results in Experiment 2

#### 4.2.6. Cations

The cations analyzed consisted of calcium, sodium, potassium, magnesium and ammonium. No ammonium was detected in any of the leachate samples. The results of calcium analysis are presented in Figure 4-26. Calcium concentrations in the single lysimeter ranged from 195 mg/L to 450 mg/L. The concentrations decreased gradually in the single lysimeter by day 200 and then remained relatively constant at approximately 200 mg/L through the remainder of the experiment. The serial lysimeter resulted in considerably higher calcium concentrations over the entire experimental period, with a range of 400 to 600 mg/L. The average of calcium concentrations in the serial lysimeter was 536 mg/L, while the single lysimeter resulted in an average concentration of 290 mg/L. In both the single and serial lysimeters, calcium concentrations did not decrease significantly over time.

The results of leachate sodium concentrations are presented in Figure 4-27. Sodium concentrations from both sets of lysimeter leachate decreased continually over time. However, the single lysimeter leachate exhibited considerably lower concentrations of sodium than that of the serial lysimeter throughout the experiment. This occurrence resulted most likely from the difference in waste depth. The average concentrations of the single lysimeter and the serial lysimeter were 37.8 mg/L and 114 mg/L, respectively.

Potassium exhibited a leaching trend similar to sodium but resulted in relatively low concentrations (Figure 4-28). The average potassium concentration of the single lysimeter was 8.3 mg/L, while the serial lysimeter leachate had an average concentration of 23.6 mg/L.

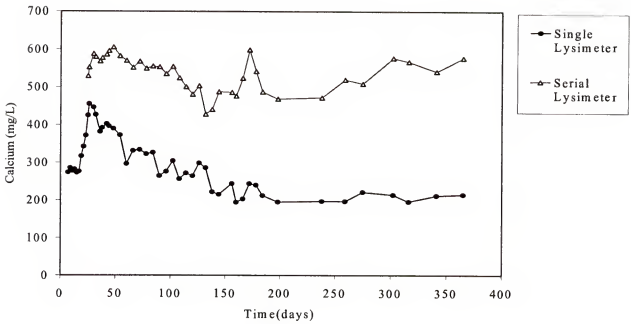


Figure 4-26 Calcium Results in Experiment 2

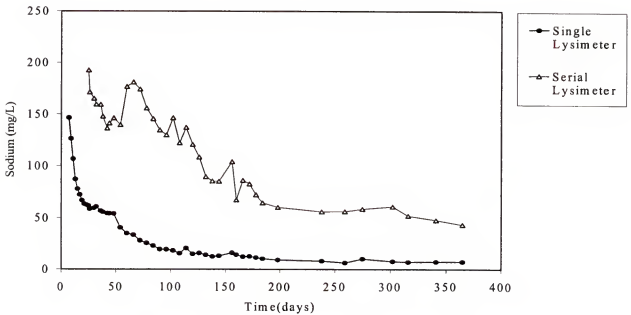
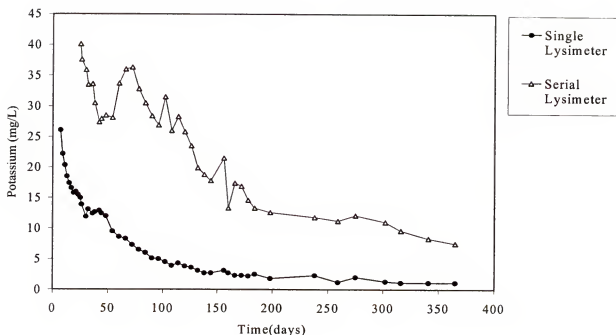
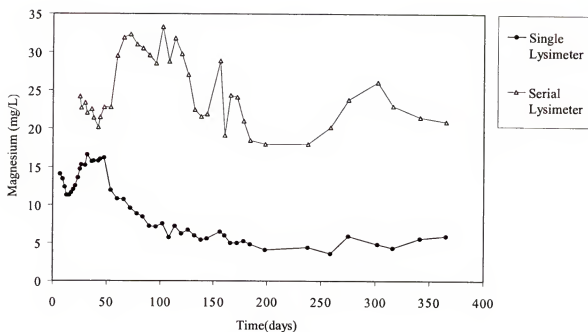


Figure 4-27 Sodium Results in Experiment 2



**Figure 4-28 Potassium Results in Experiment 2**

Figure 4-29 presents magnesium results in the leachate. Magnesium concentrations in the single lysimeter gradually decreased until day 200, after which they were nearly constant at 5 mg/L. The average concentration of magnesium in the lysimeter was 9.4 mg/L. On the other hand, the magnesium concentrations in leachate from the serial lysimeter were variable over time, ranging from 18 mg/L to 33.3 mg/L. The average concentration of 24.6 mg/L in the serial lysimeter was considerably higher than that of the single lysimeter.



**Figure 4-29 Magnesium Results in Experiment 2**

#### 4.2.7. Metals

High concentrations of metals are of great concern to human health. Based on human health considerations, the U.S. EPA established the primary drinking water standards for many metals, including arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver (CFR, 1997). In this study, six metals (arsenic, chromium, copper, iron, manganese, and zinc) were targeted for the metal analysis of the leachate. These compounds were selected because they were contained in components in the synthesized waste.

Arsenic leachate results are presented in Figure 4-30. The concentration of arsenic in the serial lysimeter began at a much higher level than the single lysimeter, decreased rapidly by day 180, and then remained constant in the range of 10 to 35  $\mu\text{g/L}$ . In the single lysimeter, arsenic concentrations followed the same downward trend with an exception of a spike present during the initial leaching period (day 20). Arsenic concentrations of leachate from the serial lysimeter were consistently higher than those of the single lysimeter for the entire experimental period. The primary drinking water standard for arsenic is 50  $\mu\text{g/L}$  (CFR, 1997). For the first four months, the arsenic concentrations in the serial lysimeter exceeded the primary standard, after which they were below the standard. In the single lysimeter, arsenic concentrations approached the standard limit by day 100, but never exceeded the limit thereafter.

Chromium results are presented in Figure 4-31. The concentration of chromium in the single lysimeter increased rapidly to 330  $\mu\text{g/L}$  by day 70, decreased dramatically over time (by day 120), and then decreased gradually to 89 to 13.3  $\mu\text{g/L}$ . On the other hand, the serial lysimeter showed variations between 71.9  $\mu\text{g/L}$  to 165  $\mu\text{g/L}$ . The average chromium concentrations from the single lysimeter and the serial lysimeter were 127  $\mu\text{g/L}$  and 125  $\mu\text{g/L}$ , respectively. The primary drinking water standard for chromium is 100  $\mu\text{g/L}$ . Chromium in the leachate from the single lysimeter was well above the limit by day 120, and thereafter never exceeded the standard until the end of the experiment. However, the serial lysimeter chromium exceeded the standard limit throughout most of the study.

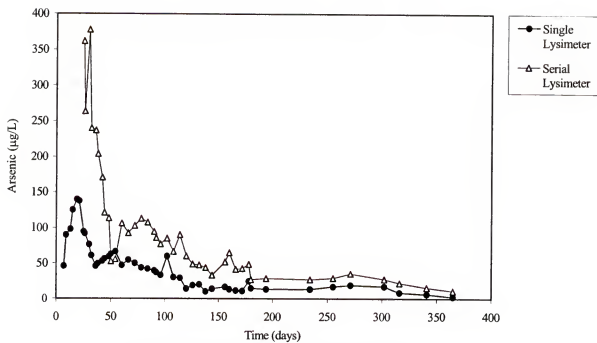


Figure 4-30 Arsenic Results in Experiment 2

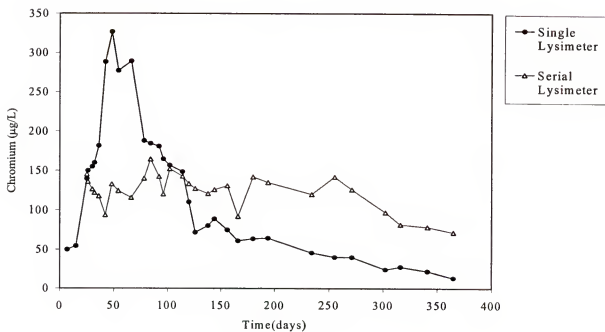


Figure 4-31 Chromium Results in Experiment 2

Figure 4-32 presents copper results in the leachate. Copper was not found in significant concentrations except during the early leaching stage of both lysimeters (day 50). The serial lysimeter started at a higher concentration than the single lysimeter and dramatically decreased over time (by day 60). Copper was not detected in the leachate for the remaining experimental period. Copper concentrations in the single lysimeter decreased rapidly from 40 µg/L to below the detection limit of 5 µg/L.

Iron was found in abundance. Iron is a common constituent of solid wastes. It is generally considered the source of the reddish-brown color of leachate (McGinley and Kmet, 1984). Iron results are presented in Figure 4-33. Iron concentrations in the single lysimeter increased rapidly to reach a peak (7.5 mg/L) and then declined dramatically to below 1 mg/L. The serial lysimeter followed a similar trend but at relatively lower concentrations. The secondary drinking water standard for iron is 300 µg/L. Throughout most of the study, the single lysimeter exceeded the standard limit. Iron in the serial lysimeter also exceeded the limit up to day 200, after which it remained below the standard limit.

Manganese results are presented in Figure 4-34. Manganese concentrations in the single lysimeter followed a decreasing trend to day 240 and then stayed fairly constant at 0.3 mg/L. However, manganese concentrations in the serial lysimeter varied as a function of time, ranging from 0.3 mg/L to 1.4 mg/L. All samples analyzed for manganese exceeded the secondary drinking water standard of 0.05 mg/L. The average concentrations of the single lysimeter and the serial lysimeter are 0.6 mg/L and 1.0 mg/L, respectively.



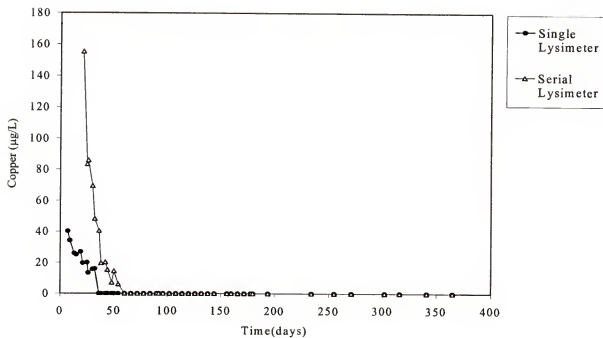


Figure 4-32 Copper Results in Experiment 2

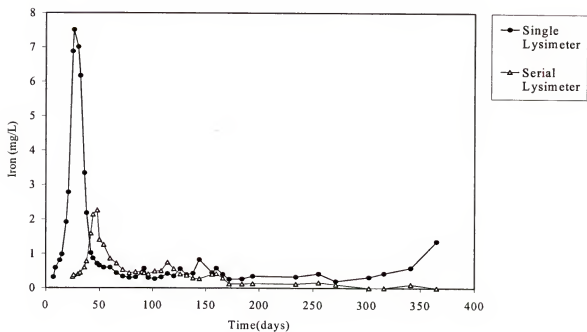
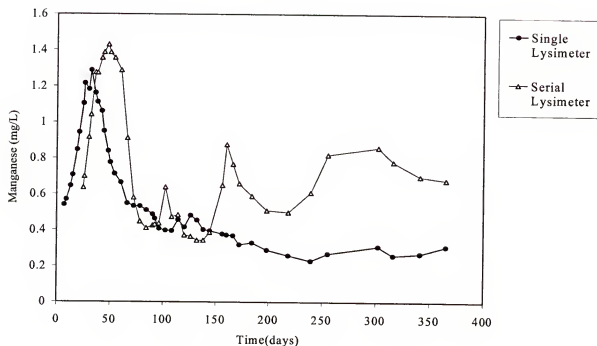
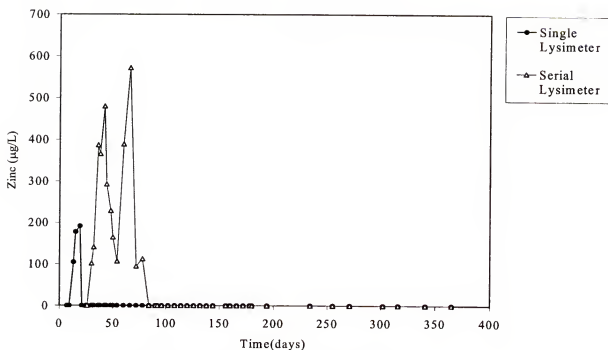


Figure 4-33 Iron Results in Experiment 2



**Figure 4-34 Manganese Results in Experiment 2**

Figure 4-35 presents zinc results of leachate. Zinc was detected from the single lysimeter only three times above the detection limit of  $100\ \mu\text{g/L}$  during the first month. In the serial lysimeter, zinc was measured in the leachate within the first 80 days, after which it was not detected above the detection limit. This occurrence also resulted most likely from metal precipitations with sulfides under anaerobic conditions. The concentration range of zinc detected in the serial lysimeter was from  $104\ \mu\text{g/L}$  to  $572\ \mu\text{g/L}$ . All samples analyzed remained below the secondary drinking water standard of  $5\ \text{mg/L}$  for zinc.



**Figure 4-35 Zinc Results in Experiment 2**

#### 4.2.8. Solid and Ion Balance

The percentage of the total mass of ions leached to the total mass of the dissolved solids measured ranged from 90% to 108%, indicating that the high concentrations of inorganic ions were responsible for the observed total dissolved solid concentrations (Table 4-4). In both set of lysimeter experiments, the major contributors to the solids balance were sulfate, alkalinity, and calcium. The remaining inorganic ions such as chloride, sulfide, sodium potassium, and magnesium were leached in small amounts during the experimental period. This occurrence was similar to other C&D waste studies investigated (Townsend et al., 1999; Weber, 1999).

**Table 4-4 Solid Balance in Experiment 2****unit: mg**

| <b>Ions</b>           |            | <b>Single Lysimeter</b> | <b>Serial Lysimeter</b> |
|-----------------------|------------|-------------------------|-------------------------|
| <b>Anion</b>          | Sulfate    | 20,576                  | 79,587                  |
|                       | Chloride   | 1,060                   | 1,648                   |
|                       | Sulfide    | 1,353                   | 2,226                   |
|                       | Alkalinity | 82,034                  | 102,621                 |
| <b>Cation</b>         | Calcium    | 44,055                  | 57,263                  |
|                       | Potassium  | 1,164                   | 2,389                   |
|                       | Magnesium  | 1,364                   | 2,587                   |
|                       | Sodium     | 5,243                   | 11,758                  |
| <b>Total (mg)</b>     |            | <b>156,849</b>          | <b>260,078</b>          |
| <b>TDS total (mg)</b> |            | <b>175,288</b>          | <b>240,358</b>          |
| <b>% Ions / TDS</b>   |            | <b>90%</b>              | <b>108%</b>             |

In addition to the TDS/ions comparison, an ion balance analysis was conducted as a means of quality assurance and ion compositions in leachate from both sets of lysimeters. The total milliequivalents (meq) in the leachate for both the inorganic anions and cations are presented in Table 4-5. In the single lysimeter, the equivalent contribution from cations was greater than that of anions (15%), while the serial lysimeter showed a good agreement between cation and anions (2%). The major anions measured in the mixed C&D waste lysimeter were sulfate and alkalinity, whereas calcium was the primary cation measured calcium. Their presence is attributed to the soluble nature of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) drywall as well as biological activity within the lysimeter. This occurrence was similar to other C&D waste studies investigated (Townsend et al., 1999; Weber, 1999).

**Table 4-5 Ion Balance in Experiment 2****unit: meq**

| <b>Ions</b>                     |             | <b>Single Lysimeter</b> | <b>Serial Lysimeter</b> |
|---------------------------------|-------------|-------------------------|-------------------------|
| <b>Anion</b>                    | Sulfate     | 429                     | 1,658                   |
|                                 | Chloride    | 30                      | 46                      |
|                                 | Sulfide     | 85                      | 139                     |
|                                 | Alkalinity  | 1,345                   | 1,682                   |
|                                 | Total (meq) | 1,888                   | 3,526                   |
| <b>Cation</b>                   | Calcium     | 2,198                   | 2,857                   |
|                                 | Potassium   | 30                      | 61                      |
|                                 | Magnesium   | 112                     | 213                     |
|                                 | Sodium      | 228                     | 511                     |
|                                 | Total (meq) | 2,568                   | 3,643                   |
| <b>% Difference<sup>a</sup></b> |             | <b>15%</b>              | <b>2%</b>               |

<sup>a</sup> (total meq of cation – total meq of anion) / (total meq of cation + total meq of anion)\* 100

#### 4.2.9. Extracted Total Mass of Pollutant from Lysimeters

With the concentrations of the chemical constituents and the volumes of the leachate being known, it was possible to estimate the total mass of pollutants leached from each lysimeter during the experiment (single and serial). The estimated quantities of extracted materials from the lysimeters during the 365-day test are presented in Table 4-6. The amount of a given pollutant leached out of the lysimeters was the summation, over a given period, of the concentration term multiplied by the volume of leachate drained from the lysimeters.

**Table 4-6 Quantities of Leached Pollutants in Experiment 2**

| <b>Parameters</b> | <b>Total Mass Leached (mg)</b> |                       | <b>Mass Ratio<br/>(Serial/Single)</b> | <b>Percent<br/>Leaching<sup>a</sup><br/>(single, serial)</b> |
|-------------------|--------------------------------|-----------------------|---------------------------------------|--|
|                   | <b>Single (4 ft)</b>           | <b>Serial (20 ft)</b> |                                       |  |
| Arsenic           | 17.3                           | 29.0                  | 1.7                                   | 2.2%, 0.7%   |
| Chromium          | 57.6                           | 64.3                  | 1.1                                   | 6.6%, 1.4%   |
| Copper            | 0.9                            | 1.4                   | 1.5                                   | 0.2%, 0.1%   |
| Sulfate           | 95,200                         | 352,000               | 3.7                                   | 0.8%, 0.3%   |
| TDS               | 581,000                        | 1,111,000             | 1.9                                   | --   |
| Chloride          | 3,100                          | 6,100                 | 2.0                                   | --   |
| Calcium           | 156,400                        | 278,000               | 1.8                                   | --   |
| Potassium         | 2,720                          | 9,540                 | 3.5                                   | --   |
| Magnesium         | 4,280                          | 12,400                | 2.9                                   | --   |
| Sodium            | 12,100                         | 46,600                | 3.8                                   | --   |
| Alkalinity        | 335,000                        | 539,000               | 1.6                                   | --   |
| Total Sulfides    | 5,920                          | 11,800                | 2.0                                   | --   |

<sup>a</sup> Mass leached/Original mass in lysimeter

Mass ratios of the serial lysimeter to the single lysimeter are given in Table 4-6. For all chemical parameters, the serial lysimeter leached more pollutants than the single lysimeter. However, all mass ratios were less than 5, ranging from 1.1 to 3.8. For the single lysimeter, the fresh leaching solution was added to the top of the lysimeter and leachate was drained, while in the serial lysimeter, leachate (not fresh leaching solution) flowed serially through the five lysimeters and was drained in the fifth lysimeter. Therefore, the mass leached in the serial lysimeter may not be exactly five times of that

in the single lysimeter. This may occur due to two probable reasons. First, since leachate was sequentially distributed in the serial lysimeters experiment, some constituents may have reached their solubility limits such that no more ions could be leached in the later lysimeters. Second, the sequential recirculation of leachate also appeared to increase pH; under those conditions, contaminant leaching may be less.

For some parameters (As, Cu, Cr,  $\text{SO}_4^{2-}$ ) where the original mass in the waste can be estimated, the percent leaching (total mass leached/original mass) was calculated and is provided in Table 4-6. The original masses of As, Cr, and Cu were obtained by multiplying the mass of the CCA-treated wood in the lysimeters by a mass percentage of the wood (mg of metal per kg of CCA-treated wood: 1,119 mg of Cu/kg of CCA-treated wood, 1,871 mg of Cr /kg of CCA-treated wood, 1,680 mg of As/kg of CCA-treated wood) (Tolaymat et al., 2000). Copper wire was excluded for the calculation of the Cu original mass. The sulfate original mass was calculated by multiplying the mass of gypsum drywall in the lysimeters by mass of sulfate in gypsum drywall (0.43 g of  $\text{SO}_4^{2-}$ /1g of gypsum drywall) (US Gypsum Company, 1995).

#### 4.3. Batch Test Results

The synthetic precipitation leaching procedure (SPLP) batch tests were conducted for evaluating the contaminant leaching potential of individual C&D waste components as well as for determining the sources of contaminants of C&D waste. The components used were the same materials as placed in the lysimeter in Experiment 1 and Experiment 2. Leachate from the batch tests were collected and analyzed for a number of chemical parameters.

#### 4.3.1. Conventional Water Quality Parameters

The conventional water quality parameters measured during batch tests included pH, specific conductance, TDS, and COD. Results of these parameters are presented in Table 4-7. The concrete batch resulted in pH above 11, which was also observed in the concrete-only lysimeter in Experiment 1. The final pH of wood and CCA-wood batch did not change very much from the leaching solution and remained below pH 5. Leachate pH from insulation, metal rebar and roofing shingle batches was greater than 9, while the pH from aluminum, cardboard, drywall, and galvanized steel batch remained near neutral (pH 6-8).

The highest specific conductance was observed from the drywall batch and was close to the maximum value observed in the drywall-only lysimeter in Experiment 1. The concrete batch also showed an elevated level of specific conductance in the leachate as a result of the dissolution of calcium carbonate species from concrete. The TDS content was greatest from the drywall batch. These observations were seen in lysimeter experiment 1.

Organics measured as COD were leached in the batch leachate from cardboard, wood, insulation, and drywall. The highest COD was measured in the cardboard batch, which was also seen with the cardboard-only lysimeter in Experiment 1. The results showed that the primary components contributing to the organic content in the C&D leachate were cardboard and wood.



**Table 4-7 Results of Conventional Water Quality Parameters from Batch Tests**

| <b>C&amp;D Waste Component</b> | <b>pH</b> | <b>Specific Conductance (<math>\mu\text{S}/\text{cm}</math>)</b> | <b>TDS (mg/L)</b> | <b>COD (mg/L)</b> |
|--------------------------------|-----------|--|-------------------|-------------------|
| Aluminum                       | 7.13      | < 20   | < 50              | < 50              |
| Cardboard                      | 6.28      | 325  | 510               | 809               |
| CCA Wood                       | 4.52      | 30   | < 50              | 130               |
| Concrete                       | 11.65     | 1,172  | 260               | < 50              |
| Copper                         | 5.17      | < 20   | < 50              | < 50              |
| Drywall                        | 7.93      | 2,360  | 2,290             | 58                |
| Steel                          | 7.08      | < 20   | < 50              | < 50              |
| Insulation                     | 9.45      | 256  | 440               | 295               |
| Metal Rebar                    | 9.38      | 55   | < 50              | < 50              |
| Roofing                        | 9.69      | 70   | < 50              | < 50              |
| Wood                           | 4.82      | 31   | < 50              | 120               |

#### 4.3.2. Ions

The results of anions measured in the batch leachates are presented in Table 4-8. The predominant anion observed in the leachate was sulfate from the drywall batch. This resulted from the soluble characteristics of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ). Some of the components such as insulation, cardboard and concrete also produced sulfate in the leachate at low levels. Nitrate and sulfate were detected in the leachate from all batch samples. This resulted from the SPLP leaching solution, which contained small amounts of sulfate ( $\text{SO}_4^{2-}$ ) and nitrate ( $\text{NO}_3^-$ ). No fluoride, nitrite, bromide, or phosphate were detected in any of the batch samples.

**Table 4-8 Results of Anions from Batch Tests**

unit: mg/L

| <b>C&amp;D Waste Component</b> | <b>Fluoride</b> | <b>Chloride</b> | <b>Nitrite</b> | <b>Bromide</b> | <b>Nitrate</b> | <b>Phosphate</b> | <b>Sulfate</b> |
|--------------------------------|-----------------|-----------------|----------------|----------------|----------------|------------------|----------------|
| Aluminum                       | < 1.0           | 3.0             | < 1.0          | < 1.0          | 4.8            | < 1.0            | 1.9            |
| Cardboard                      | < 1.0           | 6.3             | < 1.0          | < 1.0          | 12.3           | < 1.0            | 28.8           |
| CCA Wood                       | < 1.0           | 3.6             | < 1.0          | < 1.0          | 4.0            | < 1.0            | 3.6            |
| Concrete                       | < 1.0           | 3.7             | < 1.0          | < 1.0          | 3.1            | < 1.0            | 21.7           |
| Copper                         | < 1.0           | 3.0             | < 1.0          | < 1.0          | 3.2            | < 1.0            | 2.5            |
| Drywall                        | < 1.0           | 7.6             | < 1.0          | < 1.0          | 5.1            | < 1.0            | 1,430          |
| Steel                          | < 1.0           | 3.0             | < 1.0          | < 1.0          | 3.6            | < 1.0            | 2.5            |
| Insulation                     | < 1.0           | 8.2             | < 1.0          | < 1.0          | 4.3            | < 1.0            | 125            |
| Metal Rebar                    | < 1.0           | 3.2             | < 1.0          | < 1.0          | 3.7            | < 1.0            | 5.2            |
| Roofing                        | < 1.0           | 7.3             | < 1.0          | < 1.0          | 7.0            | < 1.0            | 4.2            |
| Wood                           | < 1.0           | 3.7             | < 1.0          | < 1.0          | 2.3            | < 1.0            | 2.3            |

The results of cations from the batch tests are presented in Table 4-9. The high concentration of calcium was observed in the drywall batch followed by the concrete batch. The sources of calcium are the dissolution of gypsum and calcium carbonate species from concrete. Sodium was detected in the leachate from the cardboard batch. No ammonium or magnesium was detected in the batch samples.

#### 4.3.3. Metals

Table 4-10 presents a summary of the heavy metal results. Arsenic, chromium, copper, and manganese leached in significant quantities from the CCA treated-wood batch. Another source of copper in the C&D waste components was copper wire. Manganese resulted only from the wood-containing batches (treated and untreated). No iron was detected from the entire batch samples, although iron was constantly leached

over time from the mixed C&D waste during lysimeter experiment 2. Zinc leached in a small quantity only from the galvanized steel batch.

**Table 4-9 Results of Cations from Batch Tests**

unit: mg/L

| <b>C&amp;D Waste Component</b> | <b>Sodium</b> | <b>Ammonium</b> | <b>Potassium</b> | <b>Magnesium</b> | <b>Calcium</b> |
|--------------------------------|---------------|-----------------|------------------|------------------|----------------|
| Aluminum                       | < 1.0         | < 1.0           | < 1.0            | < 1.0            | 2.4            |
| Cardboard                      | 59.7          | < 1.0           | < 1.0            | < 1.0            | < 1.0          |
| CCA Wood                       | < 1.0         | < 1.0           | 4.1              | < 1.0            | 2.5            |
| Concrete                       | 2.6           | < 1.0           | 12.0             | < 1.0            | 143            |
| Copper                         | < 1.0         | < 1.0           | < 1.0            | < 1.0            | < 1.0          |
| Drywall                        | 10.7          | < 1.0           | < 1.0            | < 1.0            | 550            |
| Steel                          | < 1.0         | < 1.0           | < 1.0            | < 1.0            | < 1.0          |
| Insulation                     | < 1.0         | < 1.0           | 1.1              | < 1.0            | < 1.0          |
| Metal Rebar                    | < 1.0         | < 1.0           | < 1.0            | < 1.0            | 8.5            |
| Roofing                        | 5.4           | < 1.0           | < 1.0            | < 1.0            | 5.1            |
| Wood                           | < 1.0         | < 1.0           | 2.1              | < 1.0            | 1.2            |

**Table 4-10 Results of Metals from Batch Tests**

| <b>C&amp;D Waste Component</b> | <b>As<br/>(µg/L)</b> | <b>Cr<br/>(µg/L)</b> | <b>Cu<br/>(µg/L)</b> | <b>Fe<br/>(mg/L)</b> | <b>Mn<br/>(mg/L)</b> | <b>Zn<br/>(mg/L)</b> |
|--------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Aluminum                       | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Cardboard                      | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| CCA Wood                       | 2,380                | 970                  | 519                  | < 0.1                | 0.14                 | < 0.1                |
| Concrete                       | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Copper                         | < 10                 | < 10                 | 1,620                | < 0.1                | < 0.1                | < 0.1                |
| Drywall                        | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Steel                          | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | 0.28                 |
| Insulation                     | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Metal Rebar                    | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Roofing                        | < 10                 | < 10                 | < 10                 | < 0.1                | < 0.1                | < 0.1                |
| Wood                           | < 10                 | < 10                 | < 10                 | < 0.1                | 0.11                 | < 0.1                |

## CHAPTER 5 DISCUSSION

This chapter discusses the results of C&D waste leachate analysis from laboratory landfill simulators. Specific areas are addressed in the following sections:

- Section 5.1 Provides a characterization of typical C&D waste leachate. The serial lysimeter in Experiment 2 is used for this discussion as it most represents actual landfill conditions
- Section 5.2 Discusses the sources of contaminants in C&D leachate based on the results of leachate from individual C&D waste components (batch and lysimeter tests)
- Section 5.3 Discusses the impact of waste depth on contaminant leaching (occurrence and concentration) based on the results in Experiment 2 (single lysimeter vs. serial lysimeter)
- Section 5.4 Discusses the changes of chemical constituent concentrations in C&D waste leachate as a function of time
- Section 5.5 Proposes phases of leachate characterization occurring in C&D waste landfills in the same manner as has been presented for municipal solid waste
- Section 5.6 Compares the results of simulated C&D leachates from different laboratory lysimeter experiments
- Section 5.7 Compares the batch results with the lysimeter results and discusses advantages and disadvantages of each leaching test
- Section 5.8 Compares the results from the laboratory C&D leachate experiments to field-scale landfill leachate data from the literature
- Section 5.9 Compares the characteristics of C&D leachate to municipal solid waste landfill leachate
- Section 5.10 Comments on the results of this study with respect to possible environmental impacts of C&D waste leachate on the environment.

## 5.1 Leachate Characteristics of Mixed C&D waste

This section provides a characterization of typical C&D waste leachate based on the laboratory study. The serial lysimeter in Experiment 2 containing mixed C&D debris was used as a basis for the characterization. Leachate from this experiment is considered to be most representative of leachate from actual C&D landfills since it simulates a 20-foot waste depth of a C&D landfill. Table 5-1 presents a summary of the results of leachate chemical constituents.

### 5.1.1 Physical Characteristics

#### 5.1.1.1 pH

The pH of an aqueous solution measures the hydrogen-ion activity electrometrically and characterizes the acidity or basicity of that solution. Leachate pH for C&D waste was approximately neutral during the experiment, which was optimum for anaerobic microbial activity (McBean et al., 1995).

#### 5.1.1.2 Oxidation reduction potential

Oxidation reduction potential (ORP) measurements are commonly used as a means of determining whether an aqueous system is aerobic and oxidizing or anaerobic and reducing (Sawyer et al., 1994). Biologically active environments can create reducing conditions, whereas contact with air leads to oxidizing conditions. Highly reduced conditions are typically found in landfill leachate, as a result of the anaerobic microbial activity, with values usually less than -200 mV (Ham et al., 1979).

**Table 5-1 Leachate Characteristics of C&D waste Landfill Simulators  
(in Experiment 2)**

| Parameters                                       | Mixed C&D Waste |       |         |
|--|-----------------|-------|---------|
|  | Min.            | Max.  | Average |
| pH   | 6.51            | 7.0   | 6.69    |
| DO (mg/L)  | 0.33            | 4.59  | 1.07    |
| ORP (mV)   | -380            | 167   | -298    |
| Specific conductance ( $\mu\text{S}/\text{cm}$ ) | 2,190           | 3,520 | 2,770   |
| TDS (mg/L)                                       | 1,640           | 3,000 | 2,300   |
| Alkalinity (mg/L as $\text{CaCO}_3$ )            | 70              | 1,280 | 852     |
| NPOC (mg/L)                                      | 19.4            | 625   | 138     |
| COD (mg/L)                                       | 90              | 625   | 296     |
| Chloride (mg/L)                                  | 5.1             | 33    | 16.2    |
| Sulfate (mg/L)                                   | 308             | 1,569 | 794     |
| Sulfide (mg/L)                                   | 0.02            | 37.4  | 21.6    |
| Calcium (mg/L)                                   | 429             | 605   | 536     |
| Magnesium (mg/L)                                 | 18              | 33.3  | 24.6    |
| Potassium (mg/L)                                 | 7.5             | 40.1  | 23.6    |
| Sodium (mg/L)                                    | 43.3            | 193   | 114     |
| Arsenic ( $\mu\text{g}/\text{L}$ )               | 10.9            | 378   | 96      |
| Chromium ( $\mu\text{g}/\text{L}$ )              | 72              | 165   | 125     |
| Copper ( $\mu\text{g}/\text{L}$ )                | 7.1             | 155   | 10      |
| Iron (mg/L)                                      | 0.1             | 2.3   | 1       |
| Manganese (mg/L)                                 | 0.3             | 1.4   | 1       |
| Zinc ( $\mu\text{g}/\text{L}$ )                  | 100             | 572   | 92      |

The average ORP value of leachate was approximately  $-300$  mV, indicating that the lysimeter was under a reduced environment throughout the experiment. Accordingly, many of the chemical constituents in the leachate would exist in reduced forms, if redox equilibrium was attained.

#### 5.1.1.3 Odor

Strong hydrogen sulfide odor and black chemical precipitates were observed in the leachate from most of the samples. This was thought to be a result of hydrogen sulfide produced by sulfate reducing bacteria (SRB) under the reduced and anaerobic environment. Properties of hydrogen sulfide include an obnoxious odor, a corrosive nature, and toxicity at high concentrations (Pomeroy and Cruse, 1969). The color of the leachate rapidly changed from clear yellow to turbid black. Many metals are known to form insoluble precipitates, black in color, in the presence of sulfides (Chen, 1974; Pomeroy and Bailey, 1981; Bhattacharyya and Ku, 1984; Lyn and Taylor, 1992).

#### 5.1.2 Chemical Characteristics

##### 5.1.2.1 Dissolved Oxygen

The dissolved oxygen (DO) concentrations consistently remained near  $1$  mg/L. When waste was first placed in the mixed waste lysimeter, the void space was filled with air. The lysimeter was then capped. While these caps provided a secure seal, they were not designed to be completely air tight.

After waste placement and capping of the lysimeters, leaching solution addition began. It is important to note that the leaching solution was not de-aired, and thus



contained dissolved oxygen (measured in the range of 6 to 8 mg of O<sub>2</sub>/L). The drop of DO in the leachate indicated that oxygen was consumed by microorganisms. DO concentrations, however, did not go to zero, but rather remained at approximately 1 mg/L. As will be discussed later, it is hypothesized that sulfate-reducing bacteria (SRB) became established in the sulfate-rich, low DO environment. It should be noted, however, that SRB are strict anaerobes and do not survive in the presence of oxygen (Sawyer et al., 1994).

The presence of both low concentrations of DO in the leachate and the occurrence of SRB activity can be reconciled by the theory that anaerobic *zones* were prevalent in the lysimeter. Some oxygen may have been present in the vapor phase, but much of the lysimeter remained anaerobic; these anaerobic zones, probably bacterial biofilms, provided a suitable environment for SRB. Once hydrogen sulfide was produced, it entered the vapor phase and subsequently partitioned into the liquid phase. Future description of the lysimeter in this discussion as *anaerobic* refers to conditions within the lysimeters that are predominantly anaerobic, but does not exclude the existence of some oxygen. It should also be noted that oxygen could have been introduced into the leachate, during the process of collecting the sample and measuring the DO. While the magnitude of DO in full-scale C&D landfills is not well known, in many cases it is likely similar in nature to the mixed C&D waste lysimeter.

#### 5.1.2.2 Dissolved solids

The concentrations of TDS ranged from 1,640 mg/L to 3,000 mg/L with an average of 2,300 mg/L. Specific conductance measurements ranged from 2.2 mS/cm to 3.5 mS/cm. Sulfate and calcium contributed most to the high concentrations of TDS in

leachate based on the solid balance analysis, as shown in Table 4-3 in the previous chapter.

Dissolved solids in leachate can be measured either by evaporating the liquid and gravimetrically determining the weight of the residue or by reading electrical conductance in a solution, which indicates the ability of the solution to carry an electrical current. Specific conductance is also used as an indirect indication of the dissolved solids, since many of the dissolved constituents are electrolytes. There was a good correlation between the specific conductance measurements and the concentrations of TDS ( $R^2 = 0.911$ ). The relationship between TDS and specific conductance was as follows: Total dissolved solids (mg/L) =  $0.88 \times$  specific conductance in  $\mu\text{S}/\text{cm} - 128$ . Based on a quick electrochemical measurement of specific conductance in leachate, TDS concentration can be roughly estimated using the relationship.

#### 5.1.2.3 Anions and Cations

Of the seven anions, sulfate and chloride were commonly detected in the leachate. High concentrations of sulfate were observed in the leachate with an average sulfate concentration of 794 mg/L, while chloride concentrations in the C&D leachate were much lower than the typical concentration ranges of MSW leachate (100 mg/L to 3,000 mg/L) (Farquhar, 1989).

Calcium leached in high concentrations compared to the other cations. Based on the ion analysis (Chapter 4.2), calcium was a predominant cation observed in leachate from the lysimeter. High levels of sulfate and calcium in the leachate are attributed to the soluble nature of gypsum drywall ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ).

#### 5.1.2.4 Sulfide Production and Sulfate Reducing Bacteria

Sulfides were present in laboratory C&D waste leachate and contributed to odors encountered problems during this study. Sulfides are formed by the microbial decomposition of sulfur-containing organic matter or from the reduction of sulfate (Hayes, 1999). Since sulfate ions are usually present in C&D waste leachate at relatively high levels because of the dissolution of gypsum drywall ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), sulfides can be produced under anaerobic conditions by sulfate reducing bacteria (SRB).

Sulfate reducing bacteria (SRB) are obligate (or strict) anaerobes, which are killed by oxygen (Stanier et al., 1986; Black, 1993; Madigan et al., 2000). They are a diverse group of bacteria that exist in anaerobic environment (Wu and Hickey, 1992). Under conditions where dissolved oxygen and nitrates are limited, sulfate serves as a source of oxygen (or as an electron acceptor) for biological reductions by SRB (Stanier et al., 1986; Wu and Hickey, 1992; Black, 1993; Sawyer et al., 1994; Nedwell and Reynolds, 1996; Mizuno et al., 1998; Hayes, 1999). Under anaerobic conditions such as in landfills, SRB reduce sulfate to sulfides and bicarbonate in the presence of organic matter. The bicarbonate ion contributes to alkalinity, which measures pH buffering capacity. The reaction can be written as follows (Dohnalek and FitzPatrick, 1983):



where,  $\text{CH}_2\text{O-R}$ : Organic matter

$\text{SO}_4^{2-}$ : Sulfate

R: Undefined radical

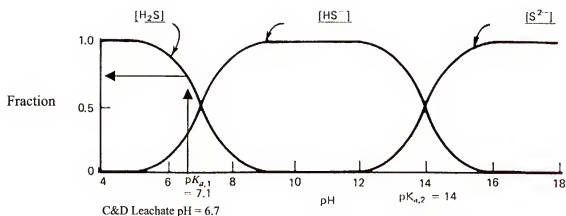
$\text{HCO}_3^-$ : Bicarbonate

$\text{H}_2\text{S}$ : hydrogen Sulfide

$\text{HS}^-$ : Hydrogen Bisulfide

$\text{S}^{2-}$ : Sulfide

The sulfate ion establishes equilibrium with hydrogen ion to form three different sulfide species ( $\text{H}_2\text{S}$ ,  $\text{HS}^-$ ,  $\text{S}^{2-}$ ) at various pH levels. Hydrogen sulfide ( $\text{H}_2\text{S}$ ) is a weak acid ( $\text{pK}_{a1} = 7.1$  @  $25^\circ\text{C}$ ), which dissociates to hydrogen bisulfide ( $\text{HS}^-$ ). At pH values of 8 and above, most of the reduced sulfur exists in solution as  $\text{HS}^-$  and  $\text{S}^{2-}$  ions (Sawyer et al., 1994). In the pH range of 6-7, which was typically observed in the laboratory C&D leachate and field studies, hydrogen sulfide and hydrogen bisulfide would be the predominant species (Figure 5-1). ). For instance, at pH 6.7 approximately 75 % of sulfide exists as hydrogen sulfide. The average sulfide concentration was 21.4 mg/L (Table 5-1).



**Figure 5-1 Distribution Diagram for Hydrogen Sulfide at  $25^\circ\text{C}$**

(Source: Snoeyink and Jenkins, 1980)

Noticeably high concentrations of sulfide were observed throughout the experiment, generating an obnoxious “rotten egg” odor (threshold odor of 0.1 g/L) (Pomeroy and Cruse, 1969).

Alkalinity, which also resulted in large part from biological activity, followed the same leaching trend as sulfide concentration as function of time. The average concentration of alkalinity in leachate was 850 mg/L (Table 5-1). Another minor source of alkalinity might be from concrete, as discussed in Chapter 4.

#### 5.1.2.5 Organic Strength

Organic content is often the most obvious indication of the degree of contamination of municipal solid waste landfill leachate. This is due to the high percentage of biologically degradable components in MSW streams (e.g. food, paper, etc). On the other hand, C&D waste streams consist mainly of inorganic, or organic components with a low degree of biodegradability (e.g. drywall, wood, concrete, etc). Thus, lower organic content in C&D leachate relative to MSW leachate would be expected. Organic matter in leachate is commonly measured by oxygen demand and total organic carbon.

The primary organic components contributing to the organic matter in the C&D waste leachate are wood and cardboard. The organic concentrations in the leachate resulted from the dissolution of organic matter into percolating liquids and the organic byproducts of waste decomposition (e.g. organic acids).

#### 5.1.2.6 Metals

C&D wastes typically contain several metal components. Examples include sheet metal, steel (structural, banding, decking, rerod), wire (e.g., copper), nails, pipe (steel, copper), brass, aluminum (siding, ducts), and fixtures. In the lysimeter experiment aluminum, copper wire, steel, and metal rebar were included. Analytical parameters for metals included arsenic, chromium, copper, iron, manganese, and zinc.

The lysimeter leachate consistently contained arsenic, chromium and manganese at appreciable levels during the experiment. However, copper, iron and zinc concentrations significantly decreased to lower levels due to metal precipitation. It is widely known that reduced sulfide reacts with the metallic ions to form insoluble sulfide precipitates under anaerobic conditions (Chen, 1974; Pomeroy and Bailey, 1981; Bhattacharyya and Ku, 1984; Lyn and Taylor, 1992). These precipitates produce a colloidal suspension that is commonly described as black water (AWWA, 1990; Lyn and Taylor, 1992). This black precipitate was observed in the leachate from the mixed C&D waste lysimeters exposed to unsaturated conditions. Since reduced sulfide was produced in high concentrations and anaerobic conditions prevailed in the lysimeter body throughout the experiment, it is likely that some metals such as copper, iron, and zinc were mostly removed in leachate by precipitation during the active stage of sulfate reducing bacteria (after 50 days).

### 5.2 Sources of Contaminants of in C&D Waste Leachate

In this section the sources of contaminants in C&D leachate are discussed based on the results of both lysimeter experiment I (four major C&D waste components) and

the synthetic precipitation leaching procedure batch tests (eleven C&D waste components). Table 5-2 presents a summary of leachate results from lysimeters containing the primary C&D waste components (i.e. concrete, cardboard, wood, drywall). Four major chemical parameters are grouped together: dissolved solids and ions, organic constituents, metals, and other water quality parameters.

### 5.2.1 Sources of Dissolved Solids and Ions

The highest total dissolved solids (TDS) concentration was observed in the drywall-only lysimeter (Table 5-2). The mixed C&D waste lysimeter (25 % drywall by volume) was had the next highest concentration. The major source of TDS was gypsum drywall ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), which is easily dissolved by percolating liquids and thus leaches inorganic ions (sulfate and calcium). Gypsum has a solubility of approximately 2,400 mg/L at 25 °C in pure water (Dean, 1973), and thus at equilibrium would result in a sulfate concentration of 1,170 mg/L. TDS and inorganic ion concentrations from other waste lysimeters were fairly low in comparison with those of the drywall-containing lysimeters. This phenomenon was also observed in specific conductance measurements in the lysimeter. Based on the solid and ion analysis, sulfate and calcium were largely responsible for dissolved solids measured by TDS.

The results of the batch tests (presented in Chapter 4-3) confirmed the sources of TDS and ions. In a batch study, the drywall batch leachate contained a large amount of dissolved solids, ions (primarily sulfate and calcium), and a relatively high specific conductance measurement.

Table 5-2 Leachate Analysis Results of Major C&amp;D Waste Components

| Parameter                    | Cardboard   |       | Concrete    |       | Wood       |      | Drywall       |       | Mixed       |       |
|------------------------------|-------------|-------|-------------|-------|------------|------|---------------|-------|-------------|-------|
|                              | Range       | Avg.  | Range       | Avg.  | Range      | Avg. | Range         | Avg.  | Range       | Avg.  |
| TDS (mg/L)                   | 216 - 619   | 332   | 182 - 482   | 363   | 114 - 390  | 204  | 1,510 - 2,190 | 1,850 | 426 - 1,860 | 1,210 |
| Specific conductance (mS/cm) | 0.12 - 0.54 | 0.38  | 0.72 - 1.65 | 1.14  | 0.1 - 0.25 | 0.17 | 1.62 - 2.45   | 1.9   | 0.72 - 2.49 | 1.57  |
| NPOC (mg/L)                  | 19.3 - 530  | 250   | 0.5 - 12.8  | 6     | 41.4 - 310 | 184  | 11.7 - 113    | 59.1  | 20.0 - 290  | 95.6  |
| COD (mg/L)                   | 244 - 1,600 | 1,010 | 10.2 - 75   | 33.2  | 306 - 898  | 648  | 71.4 - 327    | 194   | 122 - 877   | 396   |
| Chloride (mg/L)              | 4.5 - 8.9   | 5.8   | 6.8 - 15.0  | 9.7   | 3.1 - 4.6  | 3.8  | 9.2 - 26.2    | 9.5   | 4.5 - 9.0   | 6.6   |
| Sulfate (mg/L)               | 2.0 - 22.2  | 9.4   | 7.4 - 20.1  | 12.2  | 2.3 - 28.2 | 6.7  | 538 - 1,230   | 938   | 279 - 605   | 448   |
| Calcium (mg/L)               | 5.0 - 28.3  | 16    | 70.7 - 100  | 92.5  | 3.5 - 13.3 | 9.2  | 384 - 472     | 437   | 109 - 421   | 268   |
| Magnesium (mg/L)             | 1.6 - 8.5   | 4.5   | < 1.0       | < 1.0 | 4.2 - 8.0  | 5.9  | 7.9 - 15.8    | 11.7  | 3.5 - 25.9  | 16.1  |
| Potassium (mg/L)             | 2.3 - 6.0   | 4.3   | 15.2 - 47.4 | 31.8  | 4.6 - 20.9 | 14.9 | 2.4 - 6.0     | 3.7   | 8.2 - 64.1  | 34.7  |
| Sodium (mg/L)                | 19.9 - 70.2 | 47.4  | 7.3 - 44.6  | 22.7  | 1.0 - 2.4  | 1.67 | 12.5 - 42.4   | 25    | 14.3 - 51.8 | 30    |



In addition to gypsum drywall, the source of calcium was from concrete (calcium carbonate species). This was confirmed by the concrete-only lysimeter study and by the concrete batch test. The highest concentration of sodium was observed in the cardboard lysimeter in Experiment 1 as well as the batch test for cardboard.

### 5.2.2 Sources of Organic Constituents

Organic content was measured by chemical oxygen demand (COD) and organic carbon content (e.g. NPOC). A relatively high concentration of organic content was observed from the cardboard and wood lysimeters relative to that of the other lysimeters, as shown in Table 5-2. This was likely the result of both the dissolution of high molecular weight compounds and the organic byproducts (e.g. organic acids) of waste decomposition by biological activity. These lysimeters, especially the cardboard lysimeter, possessed a strong organic acid odor. Cardboard is known to be a highly biodegradable waste, and is often used in simulating MSW decomposition (Owens and Chynoweth, 1993). Leachate from wood waste landfills has been known to increase organic carbon concentrations in groundwater due to leaching of organic molecules (Sweet and Fetrow, 1975).

In batch tests, the highest organic content was detected in the cardboard batch leachate followed by insulation and wood batch leachates. It should be noted that the tests do not simulate biological activity. The organic content was most likely soluble organic matter, not organic acids. In a landfill, the organic acids typically are produced from waste decomposition processes as intermediate or end products.

### 5.2.3 Sources of Metals

Metals were not measured in lysimeter experiment 1, which mainly focused on contaminant leaching from major C&D waste components (i.e. cardboard, concrete, wood, drywall). In this discussion, sources of metals are identified and discussed based on the results of batch tests as well as the results of the lysimeter experiment 2. While five metals (arsenic, chromium, copper, manganese, and zinc) leached during the batch tests, the lysimeter leachate constantly contained iron in addition to the five metals during Experiment 2.

The source of arsenic, chromium, and copper was the chromated copper arsenate (CCA)-treated wood. Another source of copper in the C&D batch leachate was the copper wire. Manganese most likely resulted from wood. In a study of demolition waste leachate, high concentrations of manganese (17 mg/L) were also found from wood-based laboratory landfill experiments (50% by volume of total demolition waste) (Ferguson and Male, 1980). In a batch test, manganese resulted only from the wood-containing batch (untreated southern yellow pine and CCA-treated wood). No iron was detected from any of batch samples. Zinc is widely used in alloys (brass), galvanization, paint pigment, and chemicals. Zinc leached in small amounts in the galvanized steel batch. The probable source of zinc in the lysimeter leachate was galvanized steel employed in the lysimeter. In summary, Table 5-3 presents the sources of chemical constituents measured in C&D leachate.

**Table 5-3 A Summary of Sources of Contaminants in C&D Waste Leachate**

| <b>Contaminant</b> | <b>Major Source</b>                                       | <b>Minor Source</b> |
|--------------------|---|---------------------|
| TDS                | Drywall   | Concrete            |
| Sulfate            | Drywall   | --                  |
| Calcium            | Drywall   | Concrete            |
| Chloride           | Drywall   | Cardboard           |
| Magnesium          | Drywall   | Wood                |
| Potassium          | Concrete  | Wood                |
| Sodium             | Cardboard   | Drywall, Concrete   |
| Organic Matter     | Cardboard, Wood   | Insulation          |
| Arsenic            | Chromated copper arsenate (CCA)-treated wood              | --                  |
| Chromium           | Chromated copper arsenate (CCA)-treated wood              | --                  |
| Copper             | Chromated copper arsenate (CCA)-treated wood, Copper Wire | --                  |
| Manganese          | Untreated Wood, CCA-treated Wood                          | --                  |
| Zinc               | Galvanized Steel  | --                  |

### 5.3 Impact of Waste Depth on Leachate Quality

The chemical quality of leachate may vary considerably as a function of many variables such as nature of the waste placed in a landfill, landfill operations (waste density, waste depth, etc), and environmental factors (e.g., moisture content, temperature, pH, etc). Leachate characteristics obviously change with time, as wastes in a landfill

decompose. Also, the characteristics of leachate can be assumed to change as a function of landfill depth.

An examination of the data from lysimeter experiment 2 (single vs. serial) demonstrates the effect of waste depth on the composition of the leachate produced. The single lysimeter represents a 4-ft waste depth of a C&D landfill, while the serial lysimeter simulates a 20-ft waste depth of a C&D landfill.

Table 5-4 presents comparisons of chemical constituent concentrations in leachates between the single lysimeter and the serial lysimeter at the end of experiment (i.e. at day 365). Most of the chemical constituents reached steady state concentrations at the end of the experiment with the exception of iron. Concentration ratios of the serial lysimeter to the single lysimeter were also calculated to examine waste depth effect on leachate strength.

In both sets of the lysimeters, the final pH values were neutral and close to each other. Dissolved oxygen concentration in leachate from the single lysimeter was a little higher than the serial lysimeter. Oxidation reduction potential values in the serial lysimeter were lower than the single lysimeter. Lower DO concentrations and ORP values in leachate from the serial lysimeter indicate that more reduced and anaerobic conditions were established. During the more reduced and anaerobic conditions, higher hydrogen sulfide and alkalinity concentrations in leachate from the serial lysimeter was observed as a result of bioconversion of sulfate ion by sulfate reducing bacteria.

**Table 5-4 Comparisons of Leachate Concentrations Between Single Lysimeter (4 ft) and Serial Lysimeter (20 ft) at the End of the Experiment**

| Parameters                                       | Waste Depth   |                | Ratio<br>(Serial/Single) |
|--|---------------|----------------|--------------------------|
|  | Single (4 ft) | Serial (20 ft) |                          |
| pH   | 6.6           | 6.7            | 1.0                      |
| DO (mg/L)  | 1.5           | 1.0            | 0.7                      |
| ORP (mV)   | -269          | -312           | 1.2                      |
| Specific conductance ( $\mu\text{S}/\text{cm}$ ) | 1,070         | 2,420          | 2.3                      |
| TDS (mg/L)                                       | 770           | 1,900          | 2.5                      |
| Alkalinity (mg/L as $\text{CaCO}_3$ )            | 400           | 850            | 2.1                      |
| NPOC (mg/L)                                      | 15.5          | 22.7           | 1.5                      |
| COD (mg/L)                                       | 44            | 90             | 2.0                      |
| Chloride (mg/L)                                  | 3.3           | 5.1            | 1.5                      |
| Sulfate (mg/L)                                   | 240           | 720            | 3.0                      |
| Sulfide (mg/L)                                   | 5.4           | 19.3           | 3.6                      |
| Calcium (mg/L)                                   | 215           | 530            | 2.5                      |
| Magnesium (mg/L)                                 | 5.9           | 20.9           | 3.5                      |
| Potassium (mg/L)                                 | 1.1           | 7.5            | 7.0                      |
| Sodium (mg/L)                                    | 7.4           | 43.3           | 5.9                      |
| Arsenic ( $\mu\text{g}/\text{L}$ )               | < 5.0         | 10.9           | --                       |
| Chromium ( $\mu\text{g}/\text{L}$ )              | 13.3          | 71.9           | 5.4                      |
| Copper ( $\mu\text{g}/\text{L}$ )                | < 5.0         | < 5.0          | --                       |
| Iron (mg/L)                                      | 1.4           | < 0.1          | --                       |
| Manganese (mg/L)                                 | 0.3           | 0.7            | 2.3                      |
| Zinc (mg/L)                                      | < 0.1         | < 0.1          | --                       |

The concentrations of inorganic constituents (dissolved solids and ions) were distinctively different with the waste depth. The serial lysimeter leached much higher inorganic compounds such as TDS, sulfate, calcium, sodium, potassium, and magnesium than those of the single lysimeter. The ranges of concentration ratios between the single

lysimeter and the serial lysimeter were from 1.5 to 7.0 (Table 5-4). It was concluded that increased depth resulted in higher inorganic strengths as the contact time between the waste and the liquid phase increased. The results confirm previous findings that the deeper the waste layer was, the higher contaminant concentrations observed (Reitzel et al., 1992; Karnchanawong et al, 1995; Öman et al., 1999).

Unlike inorganic ions, organic constituents in the leachates, measured as COD and NPOC, appeared to be not different with the waste depth. A probable reason is that some of the organic compounds from wood and cardboard (biodegradable components) were utilized by anaerobic bacteria during the sulfate reduction processes, producing to hydrogen sulfide and alkalinity, as described in equation (1).

Arsenic, chromium, and manganese in leachate from the serial lysimeter were higher than the single lysimeter, indicating that the waste depth affected the metal concentrations in leachate. Other metal concentrations (copper, iron, zinc) in leachates from both sets of the lysimeters were near detection limits. This resulted most likely from metal precipitation, as sulfides. As mentioned previously, hydrogen sulfide reacted with metallic ions such as copper, iron, and zinc to form insoluble metal precipitates.

#### 5.4 Temporal Characterization of C&D Waste Leachate

In this section the changes of chemical constituent concentrations in C&D waste leachate as a function of time are discussed. Leachate quality data from the lysimeter experiment 2 was used to discuss the temporal characterization of the leachate.

Some inorganic ions, such as chloride, sodium, and potassium, followed a typical leaching trend over time. The contaminant concentrations in leachate generally increased

to a peak level, and then declined as a function of time. Since there were finite amounts of contaminants within the waste, leaching rates of contaminant began to level off as depletion occurred. However, specific conductance measurements, TDS, and calcium concentrations remained relatively constant throughout the experiment. This resulted from the dissolution of gypsum drywall, which for practical purpose served as a constant source. As discussed previously in the section on solids and ion balances, calcium and sulfate ions contributed the majority of the TDS concentration.

The organic strength (as COD or NPOC) of C&D waste leachate started at high levels partly due to the dissolution of organic matter into percolating liquids and the organic byproducts of biological and chemical reactions within the lysimeter (e.g. organic acids, lignin and tannic acids). It is considered that some portions of the organic matter were utilized by sulfate reducing bacteria during bioconversion of sulfate to sulfide. After day 150, organic concentrations in leachate remained relatively constant throughout the experiment.

Although the source of arsenic, copper, and chromium was chromated copper arsenate (CCA)-treated wood, these metals followed different leaching patterns. Arsenic followed a decreasing trend over time after reaching a peak value of 380  $\mu\text{g/L}$ , whereas chromium concentrations remained constantly in the range of 50 to 150  $\mu\text{g/L}$ , suggesting that chromium undergoes a different set of chemical reactions once leached from the wood. Copper was not found in significant concentrations. While this may appear counterintuitive, since chromium and arsenic originate from CCA-treated wood, it is likely that the reduced sulfides produced from sulfate-reducing bacteria removed the copper through precipitation, as discussed previously.

Like copper, under the anaerobic and reduced conditions, iron and zinc are commonly removed as a result of sulfide precipitation (Dohnalek and FitzPatrick, 1983; Lyn and Taylor, 1992). Iron and zinc leached in large quantities only during the initial leaching period when sulfide concentrations were not high enough for substantial metal precipitation. However, as sulfide concentrations increased over time under the anaerobic and more reduced conditions, iron and zinc were probably precipitated from the leachate. Hydrogen sulfide reacts with metals (iron and copper) to form black sulfide precipitates (Lyn and Taylor, 1992). This black precipitate formation was observed in the leachate.

#### 5.5 A Proposed Phase Diagram of Leachate Characteristics in C&D Waste

The chemical composition of leachate in C&D landfills changes over time. Changes occur in regard to what chemicals are present and the concentration of those chemicals. It is proposed that the progression of chemical and biological activity within a C&D debris landfill may be described by means of a series of phases. Similar attempts at characterizing phases of waste and leachate changes in MSW landfills have been previously described (Stanforth et al., 1965; Pohland and Harper, 1986; Ehrig, 1991).

Like the phases occurring within a MSW landfill, the phases occurring within a C&D waste landfill are presented in this section. It provides temporal changes of some chemical constituents in leachate in a C&D landfill as C&D wastes react with moisture. Four major phases primarily responsible for C&D waste decomposition and its resultant leachate quality are proposed, as shown in Figure 5-2.



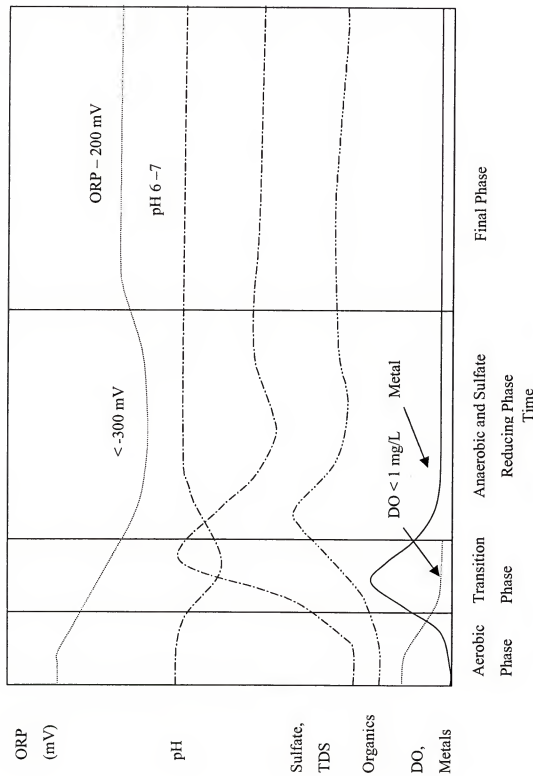


Figure 5-2 C&D Waste Leachate Characteristics and Waste Decomposition Phases

Initially, aerobic activity predominates. This phase is fairly short relative to subsequent anaerobic reactions because of the limited amount of oxygen present in a landfill. As the initial oxygen content is depleted, the anaerobic phase mainly by sulfate reducing bacteria predominates. Leachate produced during this phase would be expected to dissolve very soluble salts, such as calcium and sulfate from gypsum drywall. Leachate is typically produced from channeling through void spaces or high permeable pathways within the waste.

A transition from aerobic to anaerobic conditions occurs when field capacity is reached in the waste. During this stage, large amount of organic acids and carbon dioxide are produced, resulting in an increase of organic strength in leachate and a decrease of leachate pH. Soluble contaminants continually leach into the percolating liquid in the waste. As a more reducing and anaerobic environment is being established, sulfate reduction reactions occur with sulfate reducing bacteria. Consequently, hydrogen sulfide is formed.

After the transition phase, the next step involves anaerobic reactions mostly by sulfate reducing bacteria. These organisms produce organic acids, alkalinity and hydrogen sulfide. The most reduced condition occurs at ORP values less than  $-300$  mV. During this phase, the maximum concentration of hydrogen sulfide is also observed, generating an obnoxious odor in the leachate. The hydrogen sulfide often reacts with metallic ions to form insoluble metal precipitates. As a result, the concentrations of metals such as copper, iron, and zinc are relatively low compared to the previous phases.

During the final stage, pH values remain relatively constant between 6 and 7. Leachate becomes chemically less aggressive, containing fairly low organic strength and

decreased hydrogen sulfide and alkalinity. However, the leachate may possess calcium in high levels because gypsum drywall is served as a constant source during the dissolution process.

Leachate characteristics of the four phases above are also summarized in Table 5-5. It is noteworthy that these theoretical leaching trends over time may not be used directly for C&D landfills. Rather, by understanding the chemical characteristics of leachate observed in the laboratory studies, these results could be transferred to full-scale C&D landfills.

#### 5.6 Comparisons of Mixed C&D Waste Leachates from Lysimeter Experiments

In this section, comparisons of the results for the chemical constituents in the leachates of lysimeter experiment 1, lysimeter experiment 2 and Thurn's lysimeter study (1997) are made. Lysimeter experiment 1, which consisted of the mixed waste lysimeter, contained a mixture of four major C&D waste components (i.e. cardboard, concrete, wood, drywall) in equal volume (25 %), as described previously. The experimental period in Experiment 1 was 93 days. The single lysimeter in lysimeter experiment 2 and Thurn's lysimeter contained mixed C&D materials based on a typical composition of a mixed C&D waste stream. The single lysimeter experiment was operated over a 365-day period, while Thurn's lysimeter experiment was conducted for 72 days. Although experimental conditions among the lysimeter experiments were somewhat different, comparisons of both leachate characteristics can provide valuable information regarding conditions under which contaminant concentrations in leachate changes over time.

**Table 5-5 A Summary of Leachate Characteristics of a Proposed Phases in a C&D Debris Landfill**

| Phase 1, Initial  | Phase 2, Transition   |
|---|---|
| <ul style="list-style-type: none"> <li>• Decrease of dissolved oxygen</li> <li>• Decrease of pH (5 – 6)</li> <li>• Decrease of oxidation reduction potential</li> <li>• Increase of organic compounds</li> <li>• Increase inorganic compounds (e.g., cations and anions)</li> <li>• Increase of metal concentrations</li> </ul>   | <ul style="list-style-type: none"> <li>• Depletion of dissolved oxygen (less than 1 mg/L)</li> <li>• Decrease of pH-values (5 - 6)</li> <li>• Low oxidation reduction potential (less than –250 mV)</li> <li>• Increase of organic compounds concentrations</li> <li>• Increase of hydrogen sulfide and alkalinity</li> <li>• Increase of inorganic compounds</li> <li>• (e.g., sodium, potassium, magnesium, chloride)</li> <li>• Relatively high concentrations of calcium and sulfate</li> <li>• Increase of metal concentrations</li> </ul> |
| Phase 3, Anaerobic and Sulfate Reducing Phase   | Phase 4, Final  |
| <ul style="list-style-type: none"> <li>• Relatively constant pH-values (6 - 7)</li> <li>• Lowest oxidation reduction potential (less than –300 mV)</li> <li>• Decrease of organic compound concentrations</li> <li>• Maximum concentrations of hydrogen sulfide and alkalinity</li> <li>• Continued decrease of inorganic compounds (e.g., sodium, potassium, magnesium, chloride)</li> <li>• Relatively high concentration of calcium</li> <li>• Low metal concentrations by metal precipitations with hydrogen sulfide</li> </ul> | <ul style="list-style-type: none"> <li>• Relatively constant pH-values (6 - 7)</li> <li>• Slight increase of oxidation reduction potential</li> <li>• Low organic compound concentrations</li> <li>• Slow decrease of hydrogen sulfide and alkalinity concentrations</li> <li>• Depletion of inorganic compounds</li> <li>• (e.g., sodium, potassium, magnesium, chloride)</li> <li>• Constant concentrations of calcium and sulfate</li> <li>• Depletion of metals and continued metal precipitation with hydrogen sulfide</li> </ul>          |

Table 5-6 summarizes the experimental conditions of each experiment. It should be emphasized that there was a significant difference in the leaching solution application rates among the lysimeters. In experiment 1, approximately one gallon (3.6 liters) of the SPLP leaching fluid was added to the mixed waste lysimeter every other day at a flow rate of approximately 720-ml per minute for 5 min. The experiment simulated a 5-minute duration rainfall amounting to 5 in. of precipitation every other day.

**Table 5-6 Comparisons of Experimental Conditions from Laboratory Lysimeter Experiments**

| <b>Experimental Conditions</b>        | <b>Experiment 1 - Mixed</b>                                   | <b>Experiment 2 - Single</b>   | <b>Thurn's Experiment (Unsaturated)</b>  |
|---------------------------------------|---|--|--|
| Temperature (°C)                      | 21.0 – 24.3   | 21.1 – 24.9  | 19.5 – 24.3  |
| Waste Composition                     | Four major C&D components: cardboard, drywall, concrete, wood | 11 C&D components<br>Major: wood, concrete, roofing, drywall, cardboard<br>Minor: metal components, insulation | 8 C&D components: wood, concrete, roofing, drywall, cardboard, insulation, and metal rebar |
| Leaching Solution                     | SPLP leaching solution  | SPLP leaching solution   | Deionized water  |
| Application rate of leaching solution | 720 ml/min for 5 min every two days                           | 46 ml/min for 10 min every six hours   | 1,100 ml/min for 10 min every two days   |
| Experimental Period                   | 93 days   | 365 days   | 72 days  |
| Moisture Flow                         | Fast  | Slow   | Fast   |

In Experiment 2, 463 ml of the SPLP leaching solution was applied to the single lysimeter every six hours at a flow rate of 46.3 ml/min. The single lysimeter simulated a 10-minute duration precipitation amounting to 0.63 in. rain every six hours. A total of 5

in. of rainfall was also obtained after two days in the single lysimeter. This was approximately the same application rate (5 in.) of the SPLP leaching solution for two days to the mixed waste lysimeter in Experiment 1.

In Thurn's lysimeter study, approximately 3 gallons of deionized water was added to the unsaturated lysimeters every two days with a flow rate of 1,100-ml per minute for 10 min. This water addition resulted in a 10-minute duration rainfall to 6.3 in. of precipitation every two days.

Figure 5-3 presents the comparisons for some of the leachate results among the lysimeter experiments. Although temporal changes of pH, specific conductance, total dissolved solids and calcium were somewhat different during the early leaching stage (up to day 40 – day 60), they followed similar leaching trends following that period. At the later leaching stage pH, specific conductance levels, and TDS concentrations approached the same ranges.

One probable reason for the concentration difference during the early stage is that moisture flow in the single lysimeter was slower than those of the mixed lysimeter in Experiment 2 and the Thurn's lysimeter (Table 5-6), resulting in a longer residence time of moisture in the single lysimeter. Since sulfate (a fraction of which was converted to sulfides) and calcium leached less in the single lysimeter, lower specific conductance and TDS levels were observed in leachate. As discussed previously, sulfate and calcium were the predominant ions in C&D leachate from the mixed waste lysimeter, contributing to dissolved solid concentrations in leachate.

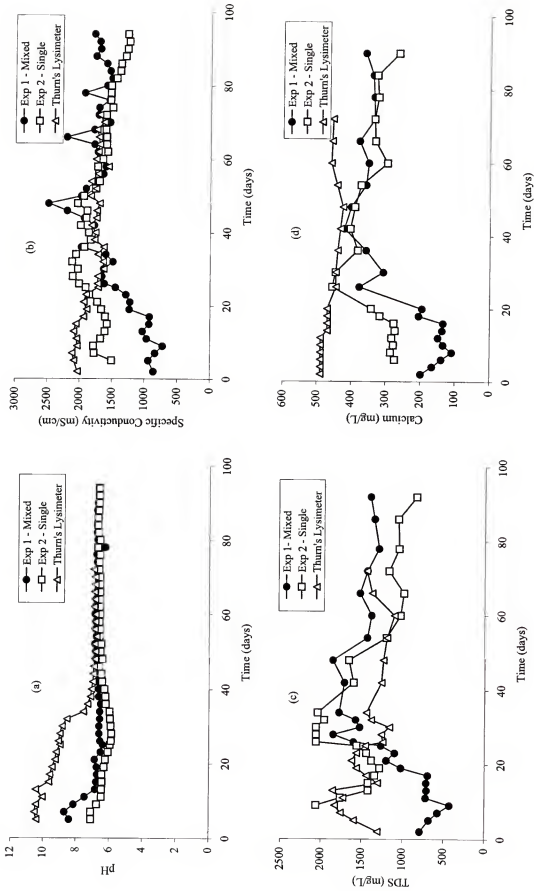


Figure 5-3 Comparisons of pH (a), Specific Conductance(b), TDS(c), and Calcium(d) Concentrations (Experiment 1, Experiment 2, and Thurn's Experiment)

Unlike pH and the dissolved solids, the leaching trend of sulfate from the single lysimeter was very different from those of the mixed lysimeter in Experiment 1 and the Thurn's lysimeter [Figure 5-4 (a)]. The sulfate concentrations from the single lysimeter began at a high level and then decreased rapidly over time, while the mixed lysimeter and the Thurn's lysimeter showed relatively constant concentrations throughout the experiment.

The two different leaching patterns are probably attributed to different modes of moisture flow within the lysimeters, which might have affected conditions of biological activity by sulfate reducing bacteria. To date, no information regarding the effect of water (or leaching solution) application rate on the activity of sulfate reducing bacteria is available.

As mentioned previously, the mixed lysimeter in Experiment 1 was subjected to the addition of approximately one gallon (3.6 liters) of the SPLP leaching solution every other day at a flow rate of approximately 720-ml per minute for 5 min, resulting in a simulated 5-minute duration rainfall amounting to 5 in. of precipitation. In Thurn's laboratory study, approximately 3 gallons of deionized water was applied to the unsaturated lysimeter every other day, resulting in a 10-minute duration rainfall to 6.3 in. of precipitation every two days. Under these conditions, moisture flow within the lysimeters was relatively fast.



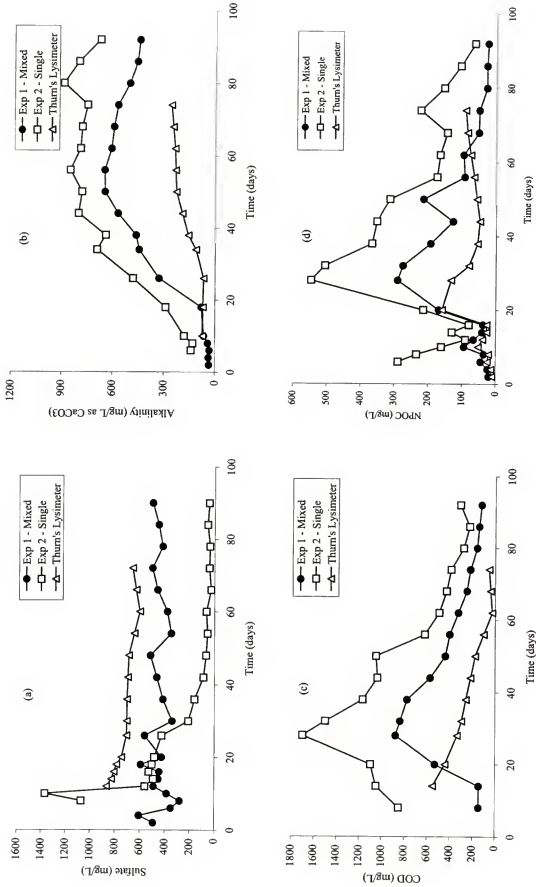


Figure 5-4 Comparisons of Sulfate (a), Alkalinity (b), COD (c), and NPOC (d) Concentrations (Experiment 1, Experiment 2, and Thurn's Experiment)

The time it took for water to percolate through the C&D waste was approximately 30 min. for the Thurn's lysimeter (Thurn, 1997) and approximately 1 hour for the mixed lysimeter in Experiment 1. Consequently, both lysimeters had a limited residence time of moisture when water (or the leaching solution) percolated through the lysimeter, resulting in relatively constant concentrations of sulfate over time probably due to the dissolution of gypsum drywall.

On the other hand, the single lysimeter in Experiment 2 was operated under a 10-minute long precipitation amounting to 0.63 in. rainfall every six hours, which is a more appropriate simulation of rainfall in the real world than the mixed lysimeter in Experiment 1 and Thurn's study. Water residence time in the single lysimeter was much slower than the other lysimeter experiments. This probably would provide better moisture conditions for microorganisms (sulfate reducing bacteria) to thrive within the C&D waste in the single lysimeter than the mixed lysimeter and Thurn's lysimeters, which seemed to be flushing-dominated systems by fast moisture flow.

Sulfate reducing bacteria probably utilized some of sulfate in a presence of organic matter, resulting in production of sulfides and alkalinity, as discussed previously. Consequently, sulfate concentrations decreased rapidly as a function of time, and alkalinity [Figure 5-4 (b)] and sulfide concentrations increased over time during sulfate reduction processes. High levels of sulfate during the early leaching stage are probably due to the soluble nature of gypsum drywall before biological activity by sulfate reducing bacteria began (day 30).

In addition, the greater residence time of moisture in the single lysimeter would lead to more organic acids and high molecular-weight compounds being formed and

dissolved into the leachate. The concentrations of organic content (COD and NPOC) in the single lysimeter were higher than the mixed lysimeter and the Thurn's lysimeter [Figure 5-4 (c), (d)].

### 5.7 Comparisons of the Results of Batch Tests with Lysimeter Experiments

Batch leaching tests have been developed to provide a quick and inexpensive method for assessing the leachability of contaminants likely to be released by a waste, and their concentration. Although leaching tests do not typically provide accurate information on the release of contaminants as a function of time, they often indicate maximum release of contaminants because they provide more rigorous leaching conditions than those in a landfill (e.g. utilization of acidic leaching solution, mechanical mixing of a leaching solution with a unit mass of waste, the length of mixing, etc). Leaching tests often fail to simulate leachate quality resulting from biological decomposition occurring in a landfill as landfilled wastes are biologically stabilized. Despite the limitations of leaching tests, regulatory agencies often require leaching tests for a waste generator to determine and classify whether a waste is potentially hazardous or innocuous.

In this section, comparisons of the leachate results of between the batch leaching tests [synthetic precipitation leaching procedure (SPLP) leaching tests] and the lysimeter experiments were made to determine the relationship between batch leaching tests and lysimeter tests. Table 5-7 presents the analytical results of leachates from the batch tests in comparison with concentration ranges of the lysimeter leachate constituents.

**Table 5-7 Leachate Analysis Results of Major C&D Waste Components**

| Parameter                    | Cardboard |             | Concrete |             | Wood   |            | Drywall |               |
|------------------------------|-----------|-------------|----------|-------------|--------|------------|---------|---------------|
|                              | Batch     | Lysimeter   | Batch    | Lysimeter   | Batch  | Lysimeter  | Batch   | Lysimeter     |
| pH                           | 6.3       | 4.3 – 6.6   | 11.7     | 11.4 – 12.1 | 4.7    | 4.3 – 6.7  | 7.9     | 5.7 – 6.7     |
| TDS (mg/L)                   | 510       | 216 - 619   | 260      | 182 - 482   | < 50   | 114 - 390  | 2,290   | 1,510 - 2,190 |
| Specific conductance (mS/cm) | 0.33      | 0.12 - 0.54 | 1.17     | 0.72 - 1.65 | < 0.02 | 0.1 - 0.25 | 2.36    | 1.62 - 2.45   |
| COD (mg/L)                   | 809       | 244 - 1,600 | < 50     | 10.2 - 75   | 120    | 306 - 898  | 58      | 71.4 - 327    |
| Sulfate (mg/L)               | 28.8      | 2.0 - 22.2  | 21.7     | 7.4 - 20.1  | 2.3    | 2.3 - 28.2 | 1,430   | 538 - 1,230   |
| Calcium (mg/L)               | < 1.0     | 5.0 - 28.3  | 143      | 70.7 - 100  | 1.2    | 3.5 - 13.3 | 550     | 384 - 472     |
| Sodium (mg/L)                | 59.7      | 19.9 - 70.2 | 2.6      | 7.3 - 44.6  | < 1.0  | 1.0 - 2.4  | 10.7    | 12.5 - 42.4   |

These results study show that inorganic parameters (e.g. TDS, sulfate, and calcium) of the drywall and concrete batches predicted fairly well, approaching to maximum concentrations of inorganic constituents of the lysimeter leachate. However, the concentrations of organic content (COD) found in leachate from the lysimeter experiment were higher than those released by the batch leaching tests for most of the C&D materials evaluated. This resulted partly from different experimental conditions. While anaerobic and reducing conditions prevailed within the lysimeter, in batch leaching tests saturated conditions were maintained using a 20:1 liquid-to-solid ratio. No biological activity in the batch tests occurred.

Metal results between the batch tests and the lysimeter experiment were also compared, as shown in Table 5-8. Some metal concentrations such as arsenic, chromium, and copper were much higher in the batch compared to the lysimeter. This is partly due to different experimental conditions of each test. During the batch test, a single C&D waste component was tested, while a mixed waste was used in the lysimeter experiment. Also, a high solid to liquid ratio (1:20) was used during the batch test, resulting in the saturated conditions. On the other hand, the unsaturated conditions were maintained in the lysimeter experiment. Iron, manganese and zinc were not measured in significant quantities during the batch tests, although the metals were released by the lysimeter test. This is partly because iron and zinc favorably leach under anaerobic and reduced conditions (Ferguson and Male, 1980).

**Table 5-8 Metal Results between Batch Tests and Lysimeter Experiment**

| Parameters                   | Batch                |                | Lysimeter Exp. 2 |
|------------------------------|----------------------|----------------|------------------|
|                              | Source of Components | Concentrations |                  |
| Arsenic ( $\mu\text{g/L}$ )  | CCA-Wood             | 2,380          | 10.9 - 378       |
| Chromium ( $\mu\text{g/L}$ ) | CCA-Wood             | 970            | 72 - 165         |
| Copper ( $\mu\text{g/L}$ )   | CCA-Wood             | 519 - 1,620    | 71 - 155         |
| Iron ( $\text{mg/L}$ )       | --                   | < 0.1          | 0.1 - 2.3        |
| Manganese ( $\text{mg/L}$ )  | Wood                 | 0.1            | 0.3 - 1.4        |
| Zinc ( $\text{mg/L}$ )       | Galvanized Steel     | 0.28           | 0.1 - 0.6        |

## 5.8 Comparisons of Laboratory C&D Leachate with Previous C&D Leachate Studies

In this section the results of this study were compared to previous C&D leachate quality data collected. Table 5-9 presents comparisons of laboratory C&D waste leachate with field-scale C&D waste landfill leachates. In most cases, the concentration ranges of leachate from the laboratory study were within the range of data reported in the literature for field C&D waste leachate. Chloride, iron, and manganese concentrations were much lower in the laboratory than in other field studies. This may result partly from the variability expected of C&D waste leachate in full-scale landfills. Also, it should be noted that landfills with higher concentrations of chloride, such as those seen in field studies in the literature, may be indicative of co-disposed municipal solid waste (MSW).

Overall, the results from the laboratory leachate quality confirm observations from previous field leachate studies. C&D waste leachate possesses inorganic constituents in high levels, primarily calcium and sulfate. The organic strength of C&D waste leachate is much less than MSW, and is dictated by components such as paper, cardboard, and wood as well as perhaps by co-disposed MSW.

Although this study provides fundamental information regarding leachate properties from mixed C&D waste, individual C&D waste, and different landfill conditions (e.g. depth), it is possible that the characteristics of C&D leachate at actual landfill sites may be different than from the laboratory studies.

Table 5-9 Comparisons of C&amp;D Laboratory Leachate Constituents Levels with Field-scale C&amp;D Waste Leachate

| Parameters       | SKB <sup>a</sup> | WMI <sup>b</sup>        | Class III Landfill in Florida | C&D Landfill Leachate <sup>c</sup> | Test Cell Leachate <sup>d</sup> | Lab Exp. 1 Leachate (Mixed) | Lab Exp. 2 Leachate (Serial) |
|------------------|------------------|-------------------------|-------------------------------|------------------------------------|---------------------------------|-----------------------------|------------------------------|
| pH               | 6.8 - 7.1        | 6.6 - 7.6               | 5.9 - 7.84                    | 6.95                               | 6.1 - 7.9                       | 6.3 - 8.7                   | 6.5 - 7.0                    |
| TDS (mg/L)       | 1,700 - 5,740    | 15 - 770                | 752 - 6,000                   | 2,263                              | 1,360 - 3,310                   | 426 - 1,856                 | 1,640 - 3,000                |
| Chloride (mg/L)  | 100 - 460        | 44.4 - 493              | 10 - 5,720                    | 158                                | 12.5 - 62.7                     | 4.5 - 9.0                   | 5.1 - 33.0                   |
| Sulfate (mg/L)   | 690 - 1,700      | 33 - 2,100              | <1.0 - 1,300                  | 254                                | 313 - 1,138                     | 279 - 605                   | 308 - 1,569                  |
| Calcium (mg/L)   | 280 - 600        | NA                      | 140 - 740                     | 274                                | 299 - 691                       | 109 - 421                   | 429 - 605                    |
| NPOC (mg/L)      | --               | 33 - 1,900 <sup>e</sup> | 359 <sup>e</sup>              | 307 <sup>e</sup>                   | 1.1 - 80.5                      | 20.0 - 290                  | 19.4 - 625                   |
| Arsenic (µg/L)   | 2.0 - 200        | 7.0 - 41.3              | --                            | 12.3                               | <5.0 - 147.8                    | --                          | 10.9 - 378                   |
| Chromium (µg/L)  | --               | 36.6 - 45               | --                            | --                                 | 6.0 - 74.9                      | --                          | 72.0 - 165                   |
| Copper (µg/L)    | 10.0             | 155                     | --                            | 20.3                               | 5.6 - 1,740                     | --                          | <5.0 - 155                   |
| Iron (mg/L)      | 20 - 14,000      | 1.4 - 48.6              | --                            | 36.8                               | 0.3 - 4.6                       | --                          | 0.1 - 2.3                    |
| Manganese (mg/L) | 80 - 9,800       | --                      | --                            | 8.7                                | 0.2 - 2.3                       | --                          | 0.3 - 1.4                    |

Note. <sup>a</sup> Source: NADC (1994), <sup>b</sup> Source: WMI (1993), <sup>c</sup> Source: Melendez (1996) Mean values, <sup>d</sup> Source: Weber (1999).

<sup>e</sup> Total organic content concentration.

One example of possible difference between field and laboratory conditions is surface area of the waste. It is generally recognized that the more waste surface area exposed to the percolating liquid, the greater the contaminant concentrations in the leachate (McCabe, 1975; Fungaroli and Steiner, 1979; van der Sloot; 1996). In this study, it was necessary to select a standard, uniform size (two inches) for all materials so that similar surface areas could be achieved and so that the waste components could fit into the lysimeter. Again, there is no standard methodology for performing landfill column leaching experiments. While landfilled C&D waste is often compacted, less waste surface area would be expected under field conditions because of the disposal of bulky items (e.g. wood, concrete, masonry, roofing materials, etc) in the mixed C&D waste stream. This could result in lower leachate constituent levels. On the other hand, deeper and more compacted waste layers conditions in actual C&D landfills might result in moisture being retained in contact with for a longer of period of time, resulting in stronger leachate.

To date, no temporal trends of C&D leachate in field-scale C&D landfills are available. This results from the limited number of existing lined C&D landfills. Temporal changes of leachate characteristics in municipal solid waste landfills have been extensively studied (Raveh and Avnimelech, 1979; Pohland and Harper, 1986; Reitzel et al., 1992; Öman et al., 1999). Therefore, no comparisons of laboratory C&D leachate to field leachate data with respect to time were made. The temporal characterization of C&D waste leachate gathered here helps to identify C&D waste leaching/decomposition processes as a function of time.



Since waste type and composition directly influence the chemical composition of leachate, knowledge of the composition of the waste deposited in C&D landfills is valuable. For example, waste composed primarily of gypsum drywall relates directly to the presence of high levels of inorganic constituents (mainly calcium and sulfate) and sulfides in leachate. Likewise, high percentages of biodegradable organic components, such as cardboard and wood, may be responsible for organic constituents in the leachate. For a mixed C&D waste stream, leachate characteristics are likely similar to those from the mixed C&D waste lysimeter. However, it should be noted that leachate chemical characteristics are not only a function of the waste composition, but also a function of other factors, which include time (or waste age), waste depth, climate (moisture conditions), and landfill operations (e.g., waste pretreatment), as discussed previously.

#### 5.9 Characteristics of C&D Leachate Relative to MSW Leachate

A comparison of the leachate constituent concentrations measured from the simulated C&D waste laboratory landfill with MSW landfill leachate with time is presented in Table 5-10. Since the chemical composition of leachate varies largely depending on the age of the landfill, leachate contaminant ranges are presented together with landfill age (three different MSW landfill age categories, 0-5 years, 5-10 years, and greater than 10 years old).

Aagain, the laboratory serial lysimeter in Experiment 2 simulated leachate quality over a 10-year monitoring period with a 20-ft waste depth in a C&D landfill. The leachate quality data obtained from the simulated laboratory C&D waste landfill are presented as a function of landfill age (Table 5-10).

Table 5-10 Comparisons of Constituents Levels of Simulated C&D Laboratory Leachate with Age Categorized MSW Leachate

| Parameters       | MSW Leachate <sup>a</sup> |                 | Simulation of Laboratory C&D Leachate Quality |               |                |                 |
|------------------|---------------------------|-----------------|---|---------------|----------------|-----------------|
|                  | 0 - 5 yr                  | 5 - 10 yr       | <10 yr  | 0 - 5 yr      | 0 - 5 yr (Ave) | 5 - 10 yr (Ave) |
| pH               | 5 - 6                     | 6 - 7           | 7 - 7.5                                       | 6.5 - 7.0     | 6.7            | 6.6 - 6.8       |
| TDS (mg/L)       | 10,000 - 25,000           | 5,000 - 10,000  | < 5000  | 1,600 - 3,000 | 2,400          | 1,700 - 2,100   |
| Chloride (mg/L)  | 1,000 - 3,000             | 500 - 2,000     | < 500   | 8.0 - 33.0    | 19.0           | 5.0 - 8.0       |
| Sulfate (mg/L)   | 500 - 2,000               | 200 - 1,000     | < 200   | 310 - 1,600   | 720            | 480 - 890       |
| Calcium (mg/L)   | 2,000 - 4,000             | 500 - 2,000     | < 500   | 430 - 610     | 540            | 470 - 580       |
| COD (mg/L)       | 15,000 - 40,000           | 10,000 - 20,000 | < 5,000                                       | 140 - 630     | 340            | 90 - 150        |
| Arsenic (µg/L)   | 1,000 - 10,000            |                 | --  | 30 - 380      | 100            | 10 - 40         |
| Chromium (µg/L)  | 1,000 - 10,000            |                 | --  | 94.0 - 160    | 130            | 70 - 140        |
| Copper (µg/L)    | 1,000 - 10,000            |                 | --  | < 5.0 - 40    | < 5.0          | < 5.0           |
| Iron (mg/L)      | 500 - 1,500               | 500 - 1,000     | < 500   | < 0.1 - 1.3   | 0.7            | 0.1 - 0.2       |
| Manganese (mg/L) | 500 - 1,500               | 500 - 1,000     | < 500   | 0.3 - 1.3     | 0.8            | 0.5 - 0.9       |
| Zinc (mg/L)      | 100 - 200                 | 50 - 100        | < 50  | < 0.1 - 0.6   | 0.12           | < 0.1           |

<sup>a</sup> Source: Farquhar (1989)

As described in Chapter 3, the first six months in the lysimeter experiment represents the first five-year operations of a C&D landfill, while the remaining six months simulated the leachate for the next five-year landfill operations in a C&D landfill (5-10yr). Thus, the C&D leachate for the first five years of simulation was obtained from the data of the first six-month laboratory lysimeter experiment. The leachate data for the next five years (5 – 10 year) was obtained from the subsequent six-month laboratory experiment.

It should be noted that leachate contaminant concentrations at certain MSW landfill sites might differ from the information provided in Table 5-10. This comparison reveals that, in most cases, the laboratory C&D leachate concentration ranges fell below all three age categorized MSW leachate levels, and were generally in the bottom half of the range.

A major exception was the concentration of sulfate. The laboratory leachate contained sulfate at high levels, which is close to the MSW leachate range (5 –10 yr), and sometimes leached much higher than MSW landfill leachate (greater than 10 years old). This should be expected for MSW leachate as MSW landfills receive only small amounts of gypsum drywall by comparison.

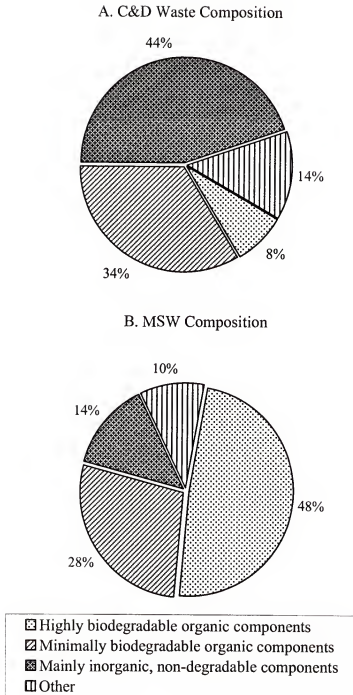
A strong and distinct odor of hydrogen sulfide would be another C&D leachate characteristic. MSW leachate does not typically have a hydrogen sulfide odor. C&D waste leachate may also contain some organic matter despite the general view of C&D waste as being inert (or non-putrid). The organic matter results from the leaching of high molecular weight organic compounds and from byproducts of decomposing organic wastes (e.g., wood, cardboard). It was observed that the C&D leachate was much lower in organic content than MSW leachate (Table 5-10). This is because of the considerably

lower percentage of biodegradable organic fractions in the C&D waste stream compared to the MSW stream.

A comparison of the biodegradable organic composition in both waste streams is made in Figure 5-5. Highly biologically degradable organic components here include food waste, paper and cardboard. Minimally biologically degradable organic components consist of wood, textiles, and plastics. Metals, glass, fine material are included in non-degradable components. The major C&D waste components include concrete, wood, cardboard, drywall and asphalt roofing shingles. The C&D waste is composed of much less readily biodegradable organic material than MSW (8 %) (Figure 5-5).

The amount of biodegradable organic material in the MSW stream has been estimated with the range of 50 % to 70 % by weight (U.S. EPA, 1998b). Some C&D waste may be composed of large or relatively bulky items. This results in less surface area for leaching, and may impact organic strength in leachate from the landfilled C&D waste.

Since leachate constituent levels in municipal solid waste (MSW) landfills are typically higher than those in C&D landfills, one disposal option for C&D debris is disposal in a lined MSW landfill. While this option is currently available, it is more expensive than disposal into unlined C&D landfills. For example, in Florida, the statewide average tipping fee per ton of waste for MSW landfills was \$ 42.69 in 1997, while the average cost of disposal of C&D waste to unlined C&D landfills was \$ 31.35 per ton (FDEP, 1998).



**Figure 5-5 Comparison of C&D Waste Composition with MSW**  
(Source. A: Lysimeter Exp. 2, B: US EPA, 1998b)

### 5.10 Assessment of Environmental Impacts of C&D Waste Leachate

Information on the chemical characteristics of C&D waste can be used for determining which chemical constituents are likely to pose a threat to groundwater beneath a landfill. In the real world setting of developing regulations, granting permits, and designing and operating landfills, the issue comes down to whether or not leachate will violate groundwater quality regulations or guidelines.

#### 5.10.1 Comparisons with Regulatory Standards to Assess Environmental Impacts

Laboratory C&D leachate quality data obtained from the serial lysimeter with mixed C&D waste in Experiment 2 were compared to primary and secondary drinking water standards. Such a comparison is not always an appropriate measure of impact on the environment, but helps to identify constituents of possible concern. In addition, drinking water standards were used because they are very frequently adopted as groundwater standards or compliance guidelines. Such is the case for Florida (FAC 1999). A primary drinking water standard is set for health-based reasons, whereas a secondary drinking water standard is a guideline regarding contaminants that may cause aesthetic effects (taste, odor, or color) in drinking water. Many states have adopted the drinking water maximum contaminant levels (MCLs) for regulating groundwater supplies. While secondary drinking water standards are not always enforceable, regulatory agencies often have the authority to control application of waste materials that will knowingly exceed such standards.

Table 5-11 presents comparisons of laboratory C&D leachate with regulatory standards. At least once, six constituents were measured at concentrations above a drinking water standard: arsenic, chromium, iron, manganese, sulfate, and total dissolved solids. The primary drinking water standards (health-based) exceeded were arsenic and chromium. Approximately two-thirds of the samples of arsenic exceeded the arsenic standard. All chromium samples exceeded the standard of 100 µg/L.

The other four constituents were secondary standards (causing aesthetic and cosmetic effects). Pollutants in the leachate that exceeded the drinking water standards by the greatest magnitude were manganese, followed by iron. The sources of manganese and iron are most likely wood, metal, and concrete, but the relative contribution from each component was not investigated further. All samples exceeded the secondary drinking water limits of 250 mg/L for sulfate and 500 mg/L for total dissolved solids (when another secondary standard is exceeded). The presence of sulfate is a concern in water supplies because of its cathartic effect upon humans when it is present in excessive amounts (Sawyer et al., 1994).

When leachate enters the groundwater beneath a landfill, the chemical constituents are expected to be diluted, and subsequent pollutant transport in the subsurface may cause attenuation. The degree of dilution and attenuation is dictated by hydrologic conditions, the rate of discharge, and the pollutant species of concern. Dilution and attenuation are often expressed by means of a dilution attenuation factor (DAF).

Table 5-11 Comparisons of C&amp;D Laboratory Leachate with Regulatory Standards

| Parameters                   | Number of Samples | Number of Detected | Number of Exceeded | Average | Maximum | DAF <sup>a</sup> for Max | Regulatory Standard |
|------------------------------|-------------------|--------------------|--------------------|---------|---------|--------------------------|---------------------|
| <b>Primary</b>               |                   |                    |                    |         |         |                          |                     |
| As ( $\mu\text{g/L}$ )       | 41                | 41                 | 25                 | 96      | 380     | 7.6                      | 50                  |
| Chromium ( $\mu\text{g/L}$ ) | 41                | 41                 | 36                 | 125     | 164     | 1.6                      | 100                 |
| <b>Secondary</b>             |                   |                    |                    |         |         |                          |                     |
| Iron ( $\text{mg/L}$ )       | 41                | 37                 | 28                 | 1.0     | 2.3     | 7.7                      | 0.3                 |
| Manganese ( $\text{mg/L}$ )  | 41                | 41                 | 41                 | 1.0     | 1.4     | 28                       | 0.05                |
| Sulfate ( $\text{mg/L}$ )    | 44                | 44                 | 44                 | 790     | 1,570   | 6.3                      | 250                 |
| TDS ( $\text{mg/L}$ )        | 47                | 47                 | 47                 | 2,300   | 3,000   | 6                        | 500                 |

<sup>a</sup> Dilution Attenuation Factor



The DAFs used in other regulatory programs range from 10 to 100 (US EPA, 1995a; US EPA, 1996), but they can be less under certain scenarios. The maximum concentrations of the chemicals of concern and the corresponding DAFs needed to meet drinking water standards are also presented in Table 5-11.

The dilution factors required to meet the arsenic standard was 2.0 for the average leachate concentration and 7.5 for the maximum leachate concentration. On the other hand, less dilution is required to meet the standard (less than 2 DAF) for chromium. While the degree of dilution needed for the arsenic concentrations to meet the standard is relatively small compared to most generic assumptions (DAF 10 –100) (US EPA, 1995a), arsenic remains a concern for two reasons. First, the National Research Council recommended that the U.S. EPA lower the current drinking water limit for arsenic (50 µg/L) (National, 1999). It has been reported that the new limit will likely be 5 or 10 µg/L. This increases the required DAF for arsenic in Table 5-11 by a factor of 20 or 75, respectively, assuming the new limit is 5 µg/L. Second, the amount of CCA in the waste stream is expected to increase in the future (Solo-Gabriele and Townsend, 1999).

A dilution factor 6 or greater would be required to meet the limits for the maximum concentrations of sulfate and TDS (Table 5-11). If the leachate from C&D waste landfills would be diluted by at least 10 in the environment, sulfate and TDS would not exceed their applicable limits without causing a problem in many cases. But it should be considered for sites with large amounts of drywall in the waste stream and with relatively little dilution of leachate. Sulfate and TDS would be routinely detected at elevated levels in the leachate because of the dissolution of gypsum drywall as constant sources of sulfate and TDS.

In previous C&D leachate studies (USEPA, 1995a; Melendez, 1996; Weber, 1999), some of the potential problematic contaminants, which may potentially pose a risk to human health and the environment, were manganese, iron, sulfate, TDS, and arsenic. It should be noted that the results from the laboratory leachate study therefore confirms observations from the previous studies.

#### 5.10.2 Potential Impact of Hydrogen Sulfide

Hydrogen sulfide is a soluble gas and may volatilize from aqueous solution into the gas phase when the partial pressure of hydrogen sulfide becomes great enough to escape from the liquid phase. Concentrations of a few tenths of milligram per liter in aqueous phase cause noticeably objectionable odors and tastes (Pomeroy and Cruse, 1969). The hydrogen sulfide production results from the bioconversion of sulfate from gypsum drywall.

Gypsum drywall, also known as wallboard or sheetrock, is a common component of most modern structures. Gypsum is an excellent fire barrier and is thus used for interior walls in both residential and commercial establishments. Gypsum drywall accounts for approximately 25% of the mass of debris generated during the construction and renovation of residential structures (USEPA, 1998a).

The presence of hydrogen sulfide in C&D waste leachate raises some concerns in terms of possible impact on the environment. Although a number of locations in the United States and Canada have been noted odor problems at C&D landfills as a result of hydrogen sulfide, hydrogen sulfide measurements from C&D leachate have not been reported in previous studies.

In this study, sulfide was always detected at high levels once the anaerobic conditions occurred in the lysimeter. The average sulfide concentration was 21.6 mg/L, generating a strong obnoxious odor (hydrogen sulfide) in the leachate. Leachate in C&D waste landfills would contain hydrogen sulfide at elevated levels under the anaerobic landfill environments. This would most likely affect the aesthetic quality (odor and color) of groundwater beneath the landfill.

## CHAPTER 6

### SUMMARY AND CONCLUSIONS

Construction and demolition (C&D) waste is usually disposed of in unlined C&D waste landfills. Unlike municipal solid waste landfills, the installation of bottom liners in C&D waste landfills is not a conventional practice in many areas of the country. It is assumed that leachate produced from C&D waste landfills is innocuous relative to that of municipal solid waste landfills and hazardous waste landfills. Therefore, C&D landfill leachate would appear to pose a little threat to the environment. Contamination of groundwater underlying the landfills may occur without a bottom liner. Only limited leachate quality data are available from actual C&D landfills to date, while numerous studies have been undertaken since the 1960's in which investigators have collected leachates from municipal solid waste and have measured their contaminant concentrations. One difficulty in collecting information on C&D waste landfill leachate is the lack of lined landfills that accept only C&D waste. Thus, little is known about the leachate quality from C&D waste landfills.

As adverse environmental impacts posed from C&D waste disposal have been documented in recent years, more information is needed to determine the true nature of C&D waste leachate and its possible impact on the environment. As a result, this experiment was performed to simulate and characterize C&D waste leachate in the laboratory and to make assessment of possible environmental impacts.

Leachate samples were collected both from laboratory lysimeters (or columns) and from synthetic precipitation leaching procedure (SPLP) batch tests. The samples were analyzed for a number of parameters. Leachate produced from the laboratory landfill simulators containing typical compositions of mixed C&D waste was chemically characterized. Leachate from individual C&D waste components (batch and lysimeter tests) was also characterized to determine the sources of contaminants in C&D leachate. Contaminant concentrations measured in the leachate from this study were compared to field C&D leachate quality as well as MSW leachate quality. Comparing the results from the leachate observed from these studies to regulatory standards provides indications of potential problematic contaminants and their possible risks to groundwater quality.

The leachate resulting from the laboratory experiments with mixed C&D waste generated a strong hydrogen sulfide odor. Sulfate-reducing bacteria under anaerobic conditions utilized dissolved sulfate from gypsum drywall and produced hydrogen sulfide. Based on solids and ion balance analyses, calcium, sulfate, and alkalinity (carbonate species) were the predominant ions observed in the leachate. The high concentrations of these ions were responsible for the majority of the dissolved solids content in the leachate.

Arsenic, chromium, iron, and manganese were leached at appreciable levels. The most likely source of arsenic and chromium was chromated copper arsenate (CCA)-treated wood. The latter two metals probably leached from concrete, wood, and metal in the waste. Copper, iron, and zinc were mostly removed in leachate by precipitation during the active decomposition stage of sulfate reducing bacteria because hydrogen sulfide reacted with the metals to form insoluble sulfide precipitates. Consequently, the

concentrations of these metals were significantly reduced once sulfate reducing conditions were established within the lysimeters.

It is widely known that leachate quality is strongly influenced by waste layer thickness. An examination of the data from the laboratory lysimeter experiment (single vs. serial) demonstrated the effect of waste depth on the composition of the leachate produced. In most cases, increased depth resulted in higher leachate constituent concentrations, as the contact time between the waste and liquid phase increased. The results demonstrated that the deeper the waste layer is, the higher the contaminant concentrations observed. These results suggest that waste depth can play a major role in the composition of leachate produced.

The concentration ranges of pollutants in leachate from the laboratory investigations were within the range of data reported in the literature for field-scale C&D waste landfills. This laboratory study confirms observations from previous reported studies. C&D waste leachate contains a large amount of inorganic constituents, primarily calcium and sulfate from the dissolution of gypsum drywall. Hydrogen sulfide resulting from the bacterial conversion of sulfate to sulfide under reducing conditions is a commonly observed phenomenon at C&D waste landfills. The organic strength of the leachate is fairly low relative to MSW leachate.

Although comparing leachate concentrations directly to drinking water standards is not always an appropriate measure of impact on the environment (dilution and attenuation processes occur in the subsurface environment), such comparisons help to identify constituents of possible concern. This study found that a few contaminants exceeded drinking water standards in laboratory C&D waste leachate. Arsenic,

chromium, iron, manganese, sulfate, and TDS exceeded their respective limits. Arsenic and chromium exceeded the primary drinking water standard. Arsenic may be of particular concern due to a lowered drinking water standard in the future as well as an increased generation rate of CCA treated wood waste in the C&D waste stream over time. Other parameters exceeded secondary standards. The contaminant in the leachate that exceeded the drinking water standard by the greatest magnitude was manganese. The most likely source of manganese was wood (treated and untreated). This is important in Florida since most drinking water is supplied by groundwater. Thus, parameters exceeding the secondary standards impair the usefulness of the water and individuals using this water may have to treat it beforehand. The extent to which violation of secondary drinking water standards should be considered is a policy decision that will be faced by environmental community in the future.

Controlled laboratory scale experiments do provide valuable data on C&D leachate quality and its formation within C&D waste landfills. While one must be careful when applying the results of laboratory tests to actual C&D landfills (e.g. particle sizes are different), the laboratory tests do shed some light on the potential impacts of C&D landfills. For example, the dissolved solids content, and in particular the concentration of sulfate, may present a problem at some C&D landfill sites. Leachate in C&D landfills would contain hydrogen sulfide at elevated levels under the anaerobic landfill environments and the conversion of sulfate to sulfides would occur in landfills. This may result in deterioration of the aesthetic quality (odor and color) of the groundwater underlying the landfill.

The results of this study indicate that leachate from well-operated C&D waste landfills is, as thought, less problematic to the environment form leachate from many other types of landfills. The research also shows, however, that unlined C&D waste landfills can negatively impact groundwater quality, especially in hydrogeologic settings where dilution is minimal. Now that most C&D debris landfills require groundwater monitoring, these data should be closely monitored in the near future. This would give the most realistic assessment of possible environmental impacts of C&D waste leachate to groundwater. Also, to elucidate the true nature of the leachate produced by the entire spectrum of C&D waste stream, further laboratory and field studies should be conducted on C&D waste with varying waste composition, waste depth and waste age under field conditions. Since arsenic and chromium routinely exceeded the primary standards in this study, the possible impact of CCA-treated wood should be further examined.



APPENDIX A  
LYSIMETER EXPERIMENT 1 - RAW DATA

Table A-1 Leachate Volume Collected in Experiment 1

unit : ml

| Sample Date | Cardboard | Concrete | Wood | Drywall | Drywall Duplicate | Mixed |
|-------------|-----------|----------|------|---------|-------------------|-------|
| 09/22/97    | 210       | 3460     | 150  | 450     | 330               | 1600  |
| 09/24/97    | 1690      | 1515     | 1240 | 700     | 240               | 1520  |
| 09/26/97    | 2050      | 2820     | 1650 | 850     | 660               | 1900  |
| 09/28/97    | 2740      | 3380     | 2070 | 1660    | 1280              | 2350  |
| 09/30/97    | 3340      | 3490     | 2450 | 1940    | 1900              | 2420  |
| 10/02/97    | 3360      | 3810     | 2710 | 2610    | 2480              | 2650  |
| 10/04/97    | 3390      | 3870     | 3000 | 2910    | 2830              | 2730  |
| 10/06/97    | 3520      | 3710     | 3260 | 2980    | 2820              | 2960  |
| 10/08/97    | 5500      | 3470     | 2870 | 3040    | 2820              | 3380  |
| 10/10/97    | 3750      | 3380     | 3040 | 3080    | 3190              | 3110  |
| 10/12/97    | 3470      | 3700     | 3140 | 3490    | 3350              | 3090  |
| 10/14/97    | 3720      | 3840     | 3180 | 3850    | 3470              | 3460  |
| 10/16/97    | 3860      | 3970     | 3230 | 3730    | 3510              | 3640  |
| 10/18/97    | 3770      | 3880     | 3120 | 3700    | 3620              | 3810  |
| 10/20/97    | 3770      | 3830     | 3160 | 3830    | 3470              | 3600  |
| 10/22/97    | 3830      | 3670     | 3350 | 3650    | 3520              | 3550  |
| 10/24/97    | 3740      | 3890     | 3440 | 3660    | 3480              | 3690  |
| 10/26/97    | 3710      | 3800     | 3300 | 3710    | 3690              | 3730  |
| 10/28/97    | 3870      | 3920     | 3330 | 3830    | 3680              | 3790  |
| 10/30/97    | 3760      | 4000     | 3400 | 3700    | 3450              | 3790  |
| 11/01/97    | 3780      | 3810     | 3300 | 3720    | 3450              | 3800  |
| 11/03/97    | 3810      | 4050     | 3390 | 3880    | 3590              | 3790  |
| 11/05/97    | 3680      | 3890     | 3480 | 3760    | 3530              | 3760  |
| 11/07/97    | 3820      | 3020     | 3370 | 3920    | 3330              | 4390  |
| 11/09/97    | 3870      | 3880     | 3410 | 3830    | 3550              | 3820  |
| 11/11/97    | 3670      | 3920     | 3480 | 3850    | 3580              | 3840  |
| 11/13/97    | 3840      | 3940     | 3480 | 3750    | 3690              | 3790  |
| 11/15/97    | 3800      | 3900     | 3520 | 3900    | 3750              | 3840  |
| 11/17/97    | 3790      | 3900     | 3600 | 3820    | 3680              | 3680  |
| 11/19/97    | 3800      | 3930     | 3490 | 3800    | 3580              | 3740  |
| 11/21/97    | 4780      | 3760     | 3510 | 3670    | 5310              | 3750  |
| 11/23/97    | 3800      | 3790     | 3400 | 3800    | 4560              | 3800  |
| 11/25/97    | 3720      | 3770     | 3430 | 3710    | 3670              | 4220  |
| 11/27/97    | 3800      | 4890     | 4300 | 3980    | 3640              | 3890  |
| 11/29/97    | 3410      | 3950     | 4920 | 4650    | 3980              | 3620  |
| 12/01/97    | 3850      | 3830     | 3470 | 3750    | 3690              | 3730  |
| 12/03/97    | 3590      | 3700     | 4310 | 3700    | 4020              | 3700  |
| 12/05/97    | 3780      | 3720     | 3430 | 3700    | 3670              | 3690  |
| 12/07/97    | 3830      | 3700     | 3800 | 3710    | 3770              | 3930  |
| 12/09/97    | 4240      | 5070     | 2590 | 3890    | 3800              | 3700  |
| 12/11/97    | 770       | 3790     | 3660 | 3770    | 3910              | 3650  |
| 12/13/97    | 3880      | 3800     | 3600 | 3810    | 3710              | 3750  |
| 12/15/97    | 3710      | 3920     | 3610 | 3630    | 3770              | 3740  |
| 12/17/97    | 3800      | 3900     | 4000 | 3770    | 3860              | 3940  |
| 12/19/97    | 3730      | 3950     | 3630 | 3810    | 3800              | 3740  |
| 12/21/97    | 3750      | 3950     | 3860 | 3690    | 3830              | 3870  |
| 12/23/97    | 3850      | 3930     | 3730 | 3720    | 3680              | 3850  |

Table A-2 pH Results in Experiment 1

| Sample Date | Cardboard | Concrete | Wood | Drywall | Drywall Duplicate | Mixed |
|-------------|-----------|----------|------|---------|-------------------|-------|
| 09/22/97    | 6.51      | 11.74    | 6.83 | 6.41    | 6.65              | 8.41  |
| 09/24/97    | 6.62      | 11.38    | 6.29 | 6.69    | 6.52              | 8.69  |
| 09/26/97    | 6.54      | 11.43    | 5.81 | 6.33    | 6.45              | 8.14  |
| 09/28/97    | 5.62      | 11.58    | 5.30 | 6.15    | 6.22              | 7.47  |
| 09/30/97    | 5.53      | 11.70    | 4.95 | 5.97    | 5.96              | 6.83  |
| 10/02/97    | 5.56      | 11.68    | 4.69 | 5.82    | 5.88              | 6.77  |
| 10/04/97    | 5.80      | 11.84    | 4.63 | 5.86    | 5.87              | 6.72  |
| 10/06/97    | 5.80      | 11.74    | 4.57 | 5.74    | 5.84              | 6.74  |
| 10/08/97    | 5.84      | 11.80    | 4.50 | 5.85    | 5.83              | 6.86  |
| 10/10/97    | 5.66      | 11.80    | 4.49 | 5.82    | 5.85              | 6.51  |
| 10/12/97    | 5.28      | 11.80    | 4.50 | 5.80    | 5.88              | 6.38  |
| 10/16/97    | 5.06      | 11.80    | 4.44 | 5.98    | 5.95              | 6.54  |
| 10/18/97    | 4.78      | 11.93    | 4.42 | 5.95    | 5.97              | 6.60  |
| 10/20/97    | 4.74      | 12.04    | 4.43 | 6.01    | 6.01              | 6.60  |
| 10/22/97    | 4.65      | 12.05    | 4.51 | 6.00    | 6.05              | 6.56  |
| 10/24/97    | 4.61      | 12.04    | 4.52 | 5.99    | 6.04              | 6.56  |
| 10/26/97    | 4.50      | 11.68    | 4.45 | 5.95    | 6.02              | 6.51  |
| 10/28/97    | 4.51      | 11.77    | 4.43 | 6.04    | 6.08              | 6.63  |
| 10/30/97    | 4.48      | 11.74    | 4.41 | 6.02    | 5.99              | 6.62  |
| 11/01/97    | 4.46      | 11.73    | 4.42 | 6.00    | 6.06              | 6.65  |
| 11/03/97    | 4.41      | 11.70    | 4.41 | 6.05    | 6.12              | 6.70  |
| 11/05/97    | 4.43      | 11.72    | 4.41 | 6.05    | 6.05              | 6.72  |
| 11/07/97    | 4.40      | 11.69    | 4.46 | 6.13    | 6.09              | 6.79  |
| 11/09/97    | 4.43      | 11.70    | 4.43 | 6.21    | 6.05              | 6.80  |
| 11/11/97    | 4.44      | 11.70    | 4.44 | 6.19    | 6.08              | 6.85  |
| 11/13/97    | 4.41      | 11.63    | 4.37 | 6.17    | 6.05              | 6.77  |
| 11/15/97    | 4.31      | 11.56    | 4.38 | 6.17    | 6.02              | 6.81  |
| 11/17/97    | 4.47      | 11.70    | 4.33 | 6.25    | 6.08              | 6.80  |
| 11/19/97    | 4.47      | 11.71    | 4.42 | 6.28    | 6.11              | 6.85  |
| 11/21/97    | 4.42      | 11.69    | 4.35 | 6.25    | 6.39              | 6.82  |
| 11/23/97    | 4.45      | 11.66    | 4.41 | 6.26    | 6.34              | 6.79  |
| 11/25/97    | 4.49      | 11.65    | 4.39 | 6.26    | 6.23              | 6.76  |
| 11/27/97    | 4.36      | 11.57    | 4.59 | 6.19    | 6.16              | 6.67  |
| 11/29/97    | 4.43      | 11.56    | 4.36 | 6.29    | 6.22              | 6.70  |
| 12/01/97    | 4.39      | 11.61    | 4.34 | 6.25    | 6.21              | 6.72  |
| 12/03/97    | 4.37      | 11.57    | 4.29 | 6.15    | 6.38              | 6.73  |
| 12/05/97    | 4.47      | 11.65    | 4.38 | 6.16    | 6.29              | 6.77  |
| 12/07/97    | 4.50      | 11.66    | 4.39 | 6.13    | 6.28              | 6.26  |
| 12/09/97    | 4.46      | 11.79    | 4.33 | 6.09    | 6.21              | 6.71  |
| 12/11/97    | 4.55      | 11.83    | 4.37 | 6.08    | 6.27              | 6.75  |
| 12/13/97    | 4.48      | 11.75    | 4.42 | 6.10    | 6.26              | 6.74  |
| 12/15/97    | 4.49      | 11.76    | 4.38 | 6.12    | 6.28              | 6.68  |
| 12/17/97    | 4.61      | 11.85    | 4.51 | 6.14    | 6.34              | 6.74  |
| 12/19/97    | 4.54      | 11.81    | 4.52 | 6.14    | 6.32              | 6.70  |
| 12/21/97    | 4.46      | 11.67    | 4.37 | 6.09    | 6.28              | 6.65  |
| 12/23/97    | 4.49      | 11.72    | 4.37 | 6.11    | 6.23              | 6.65  |

Table A-3 Dissolved Oxygen Results in Experiment 1

| Sample Date | Cardboard (mg/L) | Concrete (mg/L) | Wood (mg/L) | Drywall (mg/L) | Drywall Duplicate (mg/L) | Mixed (mg/L) |
|-------------|------------------|-----------------|-------------|----------------|--------------------------|--------------|
| 09/22/97    | 6.80             | 7.20            | 4.07        | 5.42           | 6.70                     | 3.60         |
| 09/24/97    | 6.69             | 5.95            | 2.38        | 4.24           | 4.88                     | 3.21         |
| 09/26/97    | 1.57             | 5.79            | 1.52        | 2.46           | 3.08                     | 2.42         |
| 09/28/97    | 1.08             | 7.40            | 1.33        | 2.72           | 2.17                     | 2.19         |
| 09/30/97    | 0.45             | 6.45            | 1.45        | 1.95           | 2.10                     | 1.95         |
| 10/02/97    | 0.38             | 7.30            | 0.65        | 1.22           | 1.65                     | 1.72         |
| 10/04/97    | 1.08             | 7.40            | 1.33        | 2.72           | 2.17                     | 1.48         |
| 10/06/97    | 0.45             | 7.40            | 1.45        | 1.95           | 2.10                     | 0.95         |
| 10/10/97    | 0.38             | 7.36            | 0.65        | 1.22           | 1.65                     | 0.43         |
| 10/12/97    | 1.63             | 7.50            | 1.58        | 1.59           | 1.86                     | 0.94         |
| 10/14/97    | 1.60             | 7.48            | 1.24        | 1.48           | 1.46                     | 1.14         |
| 10/16/97    | 1.70             | 8.18            | 1.25        | 0.95           | 1.45                     | 0.55         |
| 10/18/97    | 1.14             | 7.58            | 1.03        | 0.84           | 1.67                     | 0.71         |
| 10/20/97    | 1.52             | 7.60            | 1.38        | 1.52           | 1.69                     | 0.54         |
| 10/22/97    | 1.55             | 7.76            | 0.91        | 0.32           | 1.12                     | 0.20         |
| 10/24/97    | 1.58             | 7.71            | 1.15        | 0.74           | 1.15                     | 0.34         |
| 10/26/97    | 1.18             | 7.65            | 0.95        | 0.61           | 1.18                     | 0.55         |
| 10/28/97    | 1.44             | 7.84            | 1.45        | 0.71           | 1.81                     | 0.31         |
| 10/30/97    | 1.90             | 7.63            | 1.02        | 0.26           | 1.84                     | 0.36         |
| 11/01/97    | 1.90             | 7.59            | 1.51        | 0.86           | 1.80                     | 0.35         |
| 11/05/97    | 1.65             | 7.60            | 1.26        | 0.85           | 1.75                     | 0.22         |
| 11/07/97    | 1.40             | 7.75            | 1.28        | 0.73           | 1.99                     | 0.18         |
| 11/09/97    | 1.82             | 7.86            | 1.37        | 0.87           | 1.51                     | 0.30         |
| 11/11/97    | 1.76             | 7.73            | 1.37        | 0.35           | 1.77                     | 0.32         |
| 11/13/97    | 1.44             | 7.32            | 1.17        | 0.27           | 1.56                     | 0.18         |
| 11/15/97    | 1.80             | 7.68            | 1.49        | 0.84           | 1.53                     | 0.12         |
| 11/17/97    | 1.92             | 7.45            | 1.20        | 0.49           | 1.72                     | 0.17         |
| 11/19/97    | 1.30             | 7.32            | 1.06        | 0.53           | 1.92                     | 0.17         |
| 11/21/97    | 1.32             | 7.86            | 1.45        | 0.42           | 1.55                     | 0.17         |
| 11/23/97    | 1.47             | 7.75            | 1.30        | 0.26           | 1.38                     | 0.12         |
| 11/25/97    | 1.26             | 7.67            | 1.16        | 0.28           | 1.60                     | 0.16         |
| 11/27/97    | 1.14             | 7.58            | 1.07        | 0.63           | 2.07                     | 0.13         |
| 11/29/97    | 0.87             | 7.95            | 0.58        | 0.77           | 1.16                     | 0.80         |
| 12/01/97    | 1.47             | 8.08            | 1.42        | 1.14           | 1.76                     | 0.14         |
| 12/03/97    | 0.77             | 7.85            | 0.66        | 0.88           | 1.31                     | 0.70         |
| 12/05/97    | 1.00             | 7.92            | 0.68        | 0.91           | 1.11                     | 0.75         |
| 12/07/97    | 0.96             | 8.04            | 0.72        | 1.01           | 1.32                     | 0.85         |
| 12/09/97    | 0.89             | 8.06            | 0.90        | 1.01           | 1.15                     | 0.73         |
| 12/11/97    | 2.39             | 7.81            | 0.69        | 0.90           | 1.31                     | 0.12         |
| 12/13/97    | 0.75             | 7.76            | 0.68        | 1.00           | 1.08                     | 0.75         |
| 12/15/97    | 0.85             | 8.03            | 0.67        | 1.03           | 1.40                     | 0.82         |
| 12/17/97    | 0.80             | 7.90            | 0.74        | 0.93           | 1.38                     | 0.68         |
| 12/19/97    | 0.98             | 8.46            | 0.83        | 1.14           | 1.60                     | 1.00         |
| 12/21/97    | 0.88             | 8.13            | 0.76        | 0.98           | 1.22                     | 0.79         |
| 12/23/97    | 0.84             | 7.93            | 0.92        | 1.15           | 1.51                     | 0.87         |

Table A-4 ORP Results in Experiment 1

| Sample Date | Cardboard (mV) | Concrete (mV) | Wood (mV) | Drywall (mV) | Drywall Duplicate (mV) | Mixed (mV) |
|-------------|----------------|---------------|-----------|--------------|------------------------|------------|
| 09/22/97    | 285            | 76            | 324       | 353          | 351                    | 211        |
| 09/24/97    | 202            | 49            | 206       | 286          | 329                    | 206        |
| 09/26/97    | 167            | 26            | 117       | 204          | 237                    | 191        |
| 09/28/97    | 141            | 2             | 63        | 235          | 253                    | 183        |
| 10/04/97    | 127            | -22           | -20       | 88           | 36                     | 32         |
| 10/06/97    | 114            | -28           | 214       | -116         | -138                   | -33        |
| 10/08/97    | -7             | -59           | 179       | -105         | -142                   | -105       |
| 10/10/97    | -160           | -60           | 180       | -122         | -119                   | -195       |
| 10/12/97    | -145           | -80           | 165       | -130         | -120                   | -229       |
| 10/14/97    | -122           | -65           | 181       | -126         | -141                   | -255       |
| 10/16/97    | -110           | -75           | 180       | -155         | -172                   | -258       |
| 10/18/97    | -108           | -65           | 175       | -165         | -163                   | -260       |
| 10/20/97    | -95            | -58           | 195       | -170         | -156                   | -255       |
| 10/22/97    | -101           | -37           | 200       | -215         | -170                   | -260       |
| 10/24/97    | -85            | -30           | 170       | -215         | -175                   | -275       |
| 10/26/97    | -90            | -35           | 110       | -215         | -160                   | -299       |
| 10/28/97    | -55            | -48           | 85        | -235         | -155                   | -285       |
| 10/30/97    | -70            | -55           | 50        | -235         | -166                   | -305       |
| 11/01/97    | -85            | -63           | 40        | -217         | -148                   | -310       |
| 11/03/97    | -89            | -60           | 15        | -235         | -130                   | -325       |
| 11/05/97    | -83            | -65           | 15        | -235         | -148                   | -335       |
| 11/07/97    | -93            | -85           | -10       | -247         | -150                   | -349       |
| 11/09/97    | -94            | -84           | -11       | -246         | -137                   | -350       |
| 11/11/97    | -120           | -95           | -47       | -255         | -137                   | -350       |
| 11/13/97    | -113           | -86           | -45       | -259         | -115                   | -354       |
| 11/15/97    | -112           | -93           | -44       | -274         | -131                   | -362       |
| 11/17/97    | -123           | -100          | -60       | -261         | -125                   | -360       |
| 11/19/97    | -135           | -100          | -65       | -287         | -167                   | -360       |
| 11/21/97    | -142           | -101          | -89       | -293         | -100                   | -358       |
| 11/23/97    | -123           | -82           | -106      | -283         | -111                   | -365       |
| 11/25/97    | -135           | -114          | -88       | -310         | -135                   | -373       |
| 11/27/97    | -128           | -114          | -88       | -286         | -80                    | -362       |
| 11/29/97    | -129           | -114          | -80       | -291         | -119                   | -374       |
| 12/01/97    | -119           | -126          | -24       | -245         | -122                   | -368       |
| 12/05/97    | -56            | -102          | -23       | -147         | -40                    | -354       |
| 12/07/97    | -60            | -104          | -18       | -120         | -18                    | -353       |
| 12/09/97    | -69            | -101          | 5         | -115         | -37                    | -355       |
| 12/11/97    | -32            | -121          | -16       | -120         | -50                    | -334       |
| 12/13/97    | -65            | -115          | -17       | -127         | -35                    | -337       |
| 12/15/97    | -76            | -98           | -25       | -122         | -50                    | -369       |
| 12/17/97    | -56            | -120          | 2         | -98          | -124                   | -310       |
| 12/19/97    | -53            | -102          | 6         | -88          | -147                   | -307       |
| 12/21/97    | -88            | -160          | 8         | -123         | -59                    | -338       |
| 12/23/97    | -52            | -98           | -12       | -97          | -53                    | -338       |

**Table A-5 Total Dissolved Solids Results in Experiment 1**

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood (mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|-------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | NS                  | 345                | NS          | 1920              | 450                            | 790             |
| 09/26/97    | NS                  | 290                | 336         | 2110              | 1250                           | 680             |
| 09/28/97    | 620                 | 425                | 135         | 1920              | 1740                           | 570             |
| 09/30/97    | 300                 | 410                | 390         | 1860              | 1760                           | 430             |
| 10/02/97    | 290                 | 380                | 210         | 1890              | 1940                           | 720             |
| 10/04/97    | 220                 | 405                | 210         | 1740              | 2020                           | 710             |
| 10/06/97    | 340                 | 480                | 200         | 1870              | 1950                           | 710             |
| 10/08/97    | 240                 | 450                | 230         | 1800              | 2000                           | 690             |
| 10/10/97    | 420                 | 406                | 190         | 1970              | 1930                           | 1020            |
| 10/12/97    | 490                 | 395                | 300         | 1730              | 2010                           | 1200            |
| 10/14/97    | 270                 | 460                | 170         | 1700              | 1900                           | 1200            |
| 10/16/97    | 250                 | 330                | 190         | 1890              | 1980                           | 1260            |
| 10/18/97    | 255                 | 315                | 155         | 1840              | 1800                           | 1600            |
| 10/20/97    | 280                 | 390                | 195         | 2020              | 1820                           | 1850            |
| 10/22/97    | 255                 | 350                | 150         | 2130              | 1820                           | 1520            |
| 10/26/97    | 340                 | 285                | 140         | 2190              | 1880                           | 1570            |
| 11/01/97    | 420                 | 440                | 215         | 1840              | 1800                           | 1780            |
| 11/07/97    | 250                 | 240                | 115         | 1810              | 1830                           | 1710            |
| 11/13/97    | 420                 | 370                | 265         | 1790              | 1790                           | 1860            |
| 11/19/97    | 415                 | 375                | 225         | 1810              | 1740                           | 1430            |
| 11/25/97    | 270                 | 180                | 180         | 1580              | 2370                           | 1380            |
| 12/01/97    | 315                 | 384                | 180         | 1510              | 2020                           | 1520            |
| 12/07/97    | 360                 | 330                | 270         | 1930              | 2440                           | 1430            |
| 12/13/97    | 355                 | 295                | 130         | 1840              | 1910                           | 1290            |
| 12/19/97    | 340                 | 330                | 160         | 1780              | 1870                           | 1350            |
| 12/23/97    | 260                 | 350                | 145         | 1720              | 2070                           | 1400            |

**Table A-6 Specific Conductance Results in Experiment 1**

| Sample Date | Cardboard<br>(mS/cm) | Concrete<br>(mS/cm) | Wood<br>(mS/cm) | Drywall<br>(mS/cm) | Drywall<br>Duplicate<br>(mS/cm) | Mixed<br>(mS/cm) |
|-------------|----------------------|---------------------|-----------------|--------------------|---------------------------------|------------------|
| 09/22/97    | 0.12                 | 1.65                | 0.17            | 1.62               | 0.53                            | 0.86             |
| 09/24/97    | 0.18                 | 0.72                | 0.15            | 1.85               | 1.34                            | 0.94             |
| 09/26/97    | 0.17                 | 0.96                | 0.17            | 1.89               | 1.79                            | 0.84             |
| 09/28/97    | 0.26                 | 1.30                | 0.13            | 1.80               | 1.86                            | 0.72             |
| 09/30/97    | 0.36                 | 1.16                | 0.12            | 1.89               | 1.95                            | 0.97             |
| 10/02/97    | 0.35                 | 1.53                | 0.14            | 2.11               | 2.24                            | 1.03             |
| 10/04/97    | 0.36                 | 1.43                | 0.14            | 1.99               | 2.15                            | 0.93             |
| 10/08/97    | 0.43                 | 1.31                | 0.15            | 1.98               | 1.96                            | 1.23             |
| 10/10/97    | 0.27                 | 1.02                | 0.16            | 1.77               | 1.99                            | 1.22             |
| 10/12/97    | 0.41                 | 1.05                | 0.18            | 1.79               | 1.98                            | 1.29             |
| 10/14/97    | 0.36                 | 1.34                | 0.24            | 1.94               | 1.92                            | 1.45             |
| 10/16/97    | 0.40                 | 1.31                | 0.16            | 1.97               | 1.87                            | 1.62             |
| 10/18/97    | 0.41                 | 1.19                | 0.14            | 1.76               | 1.66                            | 1.66             |
| 10/20/97    | 0.45                 | 1.16                | 0.17            | 1.97               | 1.84                            | 1.63             |
| 10/24/97    | 0.47                 | 1.20                | 0.14            | 1.76               | 1.69                            | 1.60             |
| 10/26/97    | 0.54                 | 1.21                | 0.17            | 2.13               | 2.13                            | 1.98             |
| 10/28/97    | 0.48                 | 1.12                | 0.18            | 2.05               | 1.95                            | 1.80             |
| 10/30/97    | 0.37                 | 1.02                | 0.22            | 2.05               | 1.81                            | 1.86             |
| 11/01/97    | 0.43                 | 1.13                | 0.17            | 1.93               | 1.85                            | 1.78             |
| 11/03/97    | 0.40                 | 1.20                | 0.23            | 1.98               | 1.89                            | 1.93             |
| 11/05/97    | 0.51                 | 1.21                | 0.18            | 1.93               | 1.84                            | 2.20             |
| 11/07/97    | 0.42                 | 1.19                | 0.25            | 1.92               | 1.80                            | 2.49             |
| 11/09/97    | 0.47                 | 1.24                | 0.20            | 2.00               | 1.80                            | 1.98             |
| 11/11/97    | 0.49                 | 1.29                | 0.18            | 2.02               | 1.78                            | 1.91             |
| 11/13/97    | 0.38                 | 0.92                | 0.25            | 1.87               | 1.73                            | 1.75             |
| 11/15/97    | 0.48                 | 0.93                | 0.17            | 1.86               | 1.73                            | 1.64             |
| 11/17/97    | 0.50                 | 1.09                | 0.16            | 1.83               | 1.72                            | 1.61             |
| 11/19/97    | 0.48                 | 1.01                | 0.17            | 1.96               | 1.84                            | 1.66             |
| 11/21/97    | 0.47                 | 1.03                | 0.17            | 1.84               | 2.49                            | 1.73             |
| 11/23/97    | 0.36                 | 0.99                | 0.16            | 1.86               | 2.36                            | 1.78             |
| 11/25/97    | 0.48                 | 0.85                | 0.20            | 1.76               | 1.97                            | 2.21             |
| 11/27/97    | 0.49                 | 1.04                | 0.13            | 1.68               | 1.86                            | 1.79             |
| 11/29/97    | 0.36                 | 0.99                | 0.18            | 2.45               | 2.09                            | 1.55             |
| 12/01/97    | 0.37                 | 0.93                | 0.22            | 1.89               | 1.93                            | 1.72             |
| 12/03/97    | 0.47                 | 1.17                | 0.17            | 2.00               | 2.43                            | 1.71             |
| 12/05/97    | 0.43                 | 1.02                | 0.14            | 1.73               | 1.95                            | 1.55             |
| 12/07/97    | 0.31                 | 1.01                | 0.16            | 1.77               | 1.95                            | 1.94             |
| 12/09/97    | 0.31                 | 1.33                | 0.22            | 1.87               | 1.93                            | 1.59             |
| 12/11/97    | 0.43                 | 1.08                | 0.19            | 1.82               | 1.96                            | 1.52             |
| 12/13/97    | 0.43                 | 1.02                | 0.14            | 1.90               | 1.91                            | 1.55             |
| 12/15/97    | 0.34                 | 1.14                | 0.12            | 1.84               | 1.97                            | 1.60             |
| 12/17/97    | 0.26                 | 0.95                | 0.20            | 1.88               | 2.00                            | 1.77             |
| 12/19/97    | 0.24                 | 1.13                | 0.18            | 1.84               | 1.97                            | 1.70             |
| 12/21/97    | 0.25                 | 1.22                | 0.14            | 1.91               | 2.03                            | 1.71             |
| 12/23/97    | 0.32                 | 1.07                | 0.12            | 1.87               | 2.00                            | 1.79             |

Table A-7 Chemical Oxygen Demand Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood (mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed (mg/L) |
|-------------|---------------------|--------------------|-------------|-------------------|--------------------------------|--------------|
| 09/24/97    | NS*                 | NS                 | NS          | NS                | NS                             | NS           |
| 09/26/97    | NS                  | NS                 | NS          | NS                | NS                             | NS           |
| 10/02/97    | 347                 | NS                 | 306         | 81.6              | 163                            | 143          |
| 10/08/97    | 245                 | 40.8               | 429         | 163               | 204                            | 143          |
| 10/16/97    | 367                 | 40.8               | 653         | 235               | 245                            | 531          |
| 10/20/97    | 520                 | 40.8               | 735         | 306               | 184                            | 878          |
| 10/26/97    | 1224                | 20.4               | 745         | 276               | 163                            | 837          |
| 11/01/97    | 1531                | 20.4               | 806         | 327               | 122                            | 776          |
| 11/07/97    | 1582                | 20.4               | 816         | 306               | 122                            | 571          |
| 11/13/97    | 1480                | 10.2               | 898         | 265               | 124                            | 439          |
| 11/19/97    | 1600                | 75.0               | 763         | 263               | 125                            | 400          |
| 11/25/97    | 1300                | 75.0               | 625         | 175               | 138                            | 325          |
| 12/01/97    | 1200                | 50.0               | 650         | 175               | 150                            | 250          |
| 12/07/97    | 1200                | 20.0               | 640         | 100               | 60.0                           | 220          |
| 12/13/97    | 1000                | 20.2               | 580         | 80.0              | 40.0                           | 160          |
| 12/19/97    | 867                 | 20.4               | 551         | 81.6              | 81.6                           | 143          |
| 12/21/97    | 663                 | 10.2               | 520         | 71.4              | 61.2                           | 122          |



Table A-8 NPOC in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | 19.3                | 11.1               | 41.4           | 20.2              | 22.2                           | 23.6            |
| 09/26/97    | 38.8                | 10.8               | 51.9           | 26.8              | 32.4                           | 44.0            |
| 09/28/97    | 103                 | 12.8               | 79.2           | 19.6              | 40.0                           | 35.0            |
| 09/30/97    | 124                 | 12.2               | 105            | 74.9              | 79.4                           | 93.9            |
| 10/02/97    | 120                 | 10.9               | 175            | 61.0              | 78.6                           | 65.7            |
| 10/04/97    | 95.4                | 8.5                | 141            | 60.7              | 82.5                           | 40.0            |
| 10/08/97    | 59.9                | 6.5                | 224            | 37.4              | 76.5                           | 37.4            |
| 10/16/97    | 119                 | 4.4                | 250            | 71.4              | 90.4                           | 169             |
| 10/20/97    | 349                 | 3.4                | 272            | 101               | 69.8                           | 290             |
| 10/26/97    | 350                 | 4.1                | 206            | 103               | 51.6                           | 275             |
| 11/01/97    | 403                 | 4.5                | 258            | 109               | 28.9                           | 193             |
| 11/07/97    | 490                 | 4.9                | 310            | 113               | 38.3                           | 127             |
| 11/13/97    | 413                 | 2.1                | 233            | 81.6              | 29.6                           | 215             |
| 11/19/97    | 531                 | 3.6                | 250            | 89.4              | 34.2                           | 93.7            |
| 11/25/97    | 398                 | 1.6                | 202            | 68.4              | 40.0                           | 97.5            |
| 12/01/97    | 339                 | 2.9                | 170            | 38.4              | 30.0                           | 52.8            |
| 12/07/97    | 318                 | 4.2                | 210            | 50.9              | 19.2                           | 51.2            |
| 12/13/97    | 283                 | 2.7                | 241            | 29.6              | 15.3                           | 29.4            |
| 12/19/97    | 236                 | 2.5                | 147            | 14.3              | 18.2                           | 29.3            |
| 12/25/97    | 209                 | 0.5                | 114            | 11.7              | 19.8                           | 26.5            |

Table A-9 Alkalinity Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L as<br>CaCO <sub>3</sub> ) | Concrete<br>(mg/L as<br>CaCO <sub>3</sub> ) | Wood (mg/L as<br>CaCO <sub>3</sub> ) | Drywall<br>(mg/L as<br>CaCO <sub>3</sub> ) | Drywall<br>Duplicate<br>(mg/L as<br>CaCO <sub>3</sub> ) | Mixed<br>(mg/L as<br>CaCO <sub>3</sub> ) |
|-------------|--|---|--------------------------------------|--|---|--|
| 09/22/97    | NS <sup>a</sup>                              | 410   | NS                                   | 36   | NS  | 34                                       |
| 09/24/97    | NS   | 221   | 30                                   | 37   | NS  | 37                                       |
| 09/26/97    | 40   | 264   | 29                                   | 47   | 60  | 32                                       |
| 09/28/97    | 55   | 303   | 26                                   | 49   | 64  | 41                                       |
| 10/06/97    | 70   | 321   | 23                                   | 63   | 75  | 65                                       |
| 10/14/97    | 131  | 321   | BDL <sup>b</sup>                     | 122  | 113   | 80                                       |
| 10/22/97    | 84   | 322   | BDL                                  | 146  | 146   | 328                                      |
| 10/26/97    | BDL  | 310   | BDL                                  | 174  | 146   | 445                                      |
| 11/01/97    | BDL  | 312   | BDL                                  | 215  | 154   | 463                                      |
| 11/07/97    | BDL  | 322   | BDL                                  | 242  | 160   | 569                                      |
| 11/13/97    | BDL  | 313   | BDL                                  | 252  | 129   | 645                                      |
| 11/19/97    | BDL  | 314   | BDL                                  | 272  | 130   | 647                                      |
| 11/25/97    | BDL  | 305   | BDL                                  | 242  | 242   | 608                                      |
| 12/01/97    | BDL  | 313   | BDL                                  | 231  | 142   | 594                                      |
| 12/07/97    | BDL  | 301   | BDL                                  | 210  | 202   | 571                                      |
| 12/13/97    | BDL  | 348   | BDL                                  | 148  | 139   | 503                                      |
| 12/19/97    | BDL  | 312   | BDL                                  | 134  | 140   | 459                                      |
| 12/23/97    | BDL  | 314   | BDL                                  | 134  | 140   | 445                                      |

Table A-10 Sulfate Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/22/97    | NS <sup>a</sup>     | NS                 | NS             | 1130              | NS                             | 490             |
| 09/24/97    | NS                  | 20.1               | 28.2           | 1260              | 870                            | 605             |
| 09/26/97    | 21.9                | 18.5               | 14.1           | 1210              | 1180                           | 350             |
| 09/28/97    | 22.1                | 18.6               | 9.0            | 1130              | 1170                           | 280             |
| 09/30/97    | 22.2                | 17.7               | 7.4            | 1160              | 1170                           | 380             |
| 10/02/97    | 19.9                | 15.8               | 7.3            | 1150              | 1230                           | 490             |
| 10/04/97    | 17.8                | 14.4               | 7.0            | 1120              | 1220                           | 450             |
| 10/06/97    | 16.5                | 14.4               | 6.6            | 1050              | 1130                           | 440             |
| 10/08/97    | 18.4                | 12.9               | 6.4            | 1080              | 1070                           | 590             |
| 10/16/97    | 11.4                | 11.4               | 5.6            | 810               | 970                            | 430             |
| 10/20/97    | 6.0                 | 10.9               | 5.5            | 830               | 870                            | 560             |
| 10/26/97    | 4.9                 | 10.7               | 5.4            | 780               | 890                            | 340             |
| 11/01/97    | 2.8                 | 9.7                | 5.0            | 840               | 890                            | 420             |
| 11/07/97    | 2.0                 | 9.0                | 4.3            | 760               | 850                            | 460             |
| 11/13/97    | 2.0                 | 9.1                | 3.2            | 890               | 930                            | 520             |
| 11/19/97    | 2.1                 | 9.3                | 2.3            | 790               | 970                            | 350             |
| 11/25/97    | 3.4                 | 9.5                | 3.6            | 750               | 960                            | 380             |
| 12/01/97    | 3.3                 | 12.1               | 2.7            | 740               | 950                            | 460             |
| 12/07/97    | 2.8                 | 8.5                | 3.6            | 810               | 970                            | 500             |
| 12/13/97    | 2.8                 | 9.6                | 2.9            | 890               | 1000                           | 420             |
| 12/19/97    | 2.8                 | 7.4                | 7.3            | 540               | 980                            | 450             |
| 12/25/97    | 2.0                 | 7.5                | 2.8            | 950               | 1010                           | 500             |

Table A-11 Chloride Results in Experiment 1

| Sample Date | Cardboard (mg/L) | Concrete (mg/L) | Wood (mg/L) | Drywall (mg/L) | Drywall Duplicate (mg/L) | Mixed (mg/L) |
|-------------|------------------|-----------------|-------------|----------------|--------------------------|--------------|
| 09/24/97    | NS               | 8.6             | 6.5         | 10.1           | 9.4                      | 6.7          |
| 09/26/97    | 6.9              | 12.6            | 4.6         | 10.3           | 13.0                     | 6.2          |
| 09/28/97    | 8.3              | 15.0            | 3.9         | 10.3           | 16.1                     | 6.0          |
| 09/30/97    | 8.9              | 14.3            | 3.9         | 14.4           | 19.2                     | 7.8          |
| 10/02/97    | 7.0              | 13.0            | 3.8         | 15.2           | 22.6                     | 7.0          |
| 10/04/97    | 6.6              | 12.3            | 3.9         | 16.6           | 23.8                     | 6.8          |
| 10/06/97    | 6.5              | 12.4            | 4.2         | 17.4           | 24.7                     | 7.3          |
| 10/08/97    | 6.4              | 11.2            | 4.2         | 26.3           | 26.4                     | 9.0          |
| 10/16/97    | 5.2              | 10.1            | 3.5         | 17.8           | 24.7                     | 8.5          |
| 10/20/97    | 4.9              | 9.4             | 3.4         | 21.3           | 22.2                     | 9.0          |
| 10/26/97    | 5.4              | 9.1             | 3.4         | 20.3           | 23.6                     | 8.3          |
| 11/01/97    | 5.3              | 8.5             | 3.3         | 20.7           | 20.3                     | 7.9          |
| 11/07/97    | 4.7              | 7.9             | 3.3         | 17.2           | 20.0                     | 6.7          |
| 11/13/97    | 4.6              | 7.8             | 3.1         | 17.0           | 16.5                     | 5.9          |
| 11/19/97    | 4.7              | 7.8             | 3.1         | 13.5           | 15.5                     | 5.1          |
| 11/25/97    | 5.4              | 7.9             | 3.8         | 13.4           | 19.1                     | 5.6          |
| 12/01/97    | 5.6              | 7.4             | 4.0         | 12.3           | 15.5                     | 5.5          |
| 12/07/97    | 5.2              | 7.5             | 3.9         | 11.8           | 14.2                     | 5.2          |
| 12/13/97    | 5.1              | 7.4             | 3.7         | 10.4           | 12.2                     | 4.9          |
| 12/19/97    | 4.9              | 6.8             | 3.9         | 9.9            | 11.6                     | 4.6          |
| 12/25/97    | 4.5              | 6.8             | 3.6         | 9.2            | 10.3                     | 4.5          |

Table A-12 Bromide Results in Experiment 1

| Sample Date | Cardboard (mg/L) | Concrete (mg/L) | Wood (mg/L) | Drywall (mg/L) | Drywall Duplicate (mg/L) | Mixed (mg/L) |
|-------------|------------------|-----------------|-------------|----------------|--------------------------|--------------|
| 09/24/97    | BDL <sup>a</sup> | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 09/26/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 09/28/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 09/30/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/02/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/04/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/06/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/08/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/16/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/20/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 10/26/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 11/01/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 11/07/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 11/13/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 11/19/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 11/25/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 12/01/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 12/07/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 12/13/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 12/19/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |
| 12/23/97    | BDL              | BDL             | BDL         | BDL            | BDL                      | BDL          |

<sup>a</sup> Below Detection Limit (BDL): 1.0 mg/L

Table A-13 Nitrate Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | BDL*                | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/28/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/30/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/02/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/04/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/06/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/08/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/16/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/20/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/25/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/23/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |

\* Below Detection Limit (BDL): 1.0 mg/L

Table A-14 Nitrite Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | BDL <sup>a</sup>    | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/28/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/30/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/02/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/04/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/06/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/08/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/16/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/20/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/25/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/23/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |

<sup>a</sup> Below Detection Limit (BDL): 1.0 mg/L

**Table A-15 Phosphate Results in Experiment 1**

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | BDL <sup>a</sup>    | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/28/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 09/30/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/02/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/04/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/06/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/08/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/16/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/20/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 10/26/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 11/25/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/01/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/07/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/13/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/19/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |
| 12/23/97    | BDL                 | BDL                | BDL            | BDL               | BDL                            | BDL             |

<sup>a</sup> Below Detection Limit (BDL): 1.0 mg/L



**Table A-16 Ammonium Results in Experiment 1**

| <b>Sample Date</b> | <b>Cardboard<br/>(mg/L)</b> | <b>Concrete<br/>(mg/L)</b> | <b>Wood<br/>(mg/L)</b> | <b>Drywall<br/>(mg/L)</b> | <b>Drywall<br/>Duplicate<br/>(mg/L)</b> | <b>Mixed<br/>(mg/L)</b> |
|--------------------|-----------------------------|----------------------------|------------------------|---------------------------|---|-------------------------|
| 09/24/97           | BDL*                        | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 09/26/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 09/28/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 09/30/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/02/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/04/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/06/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/08/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/16/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/20/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 10/26/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 11/01/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 11/07/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 11/13/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 11/19/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 11/25/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 12/01/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 12/07/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 12/13/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 12/19/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |
| 12/23/97           | BDL                         | BDL                        | BDL                    | BDL                       | BDL                                     | BDL                     |

\* Below Detection Limit (BDL): 1.0 mg/L

Table A-17 Calcium Results in Experiment I

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | 9.4                 | 70.8               | 16.5           | 477               | 460                            | 166             |
| 09/26/97    | 6.8                 | 71.7               | 13.3           | 462               | 424                            | 139             |
| 09/28/97    | 6.8                 | 80.4               | 10.5           | 395               | 463                            | 109             |
| 09/30/97    | 6.4                 | 80.5               | 8.6            | 385               | 442                            | 134             |
| 10/02/97    | 5.5                 | 89.1               | 8.7            | 454               | 484                            | 149             |
| 10/04/97    | 5.1                 | 89.2               | 8.3            | 455               | 480                            | 137             |
| 10/06/97    | 5.0                 | 89.8               | 8.0            | 458               | 461                            | 134             |
| 10/08/97    | 8.4                 | 92.2               | 7.6            | 444               | 447                            | 204             |
| 10/16/97    | 8.1                 | 94.0               | 3.5            | 409               | 460                            | 195             |
| 10/20/97    | 17.9                | 85.0               | 6.9            | 452               | 436                            | 377             |
| 10/26/97    | 21.2                | 89.2               | 11.7           | 432               | 432                            | 307             |
| 11/01/97    | 28.3                | 94.4               | 12.2           | 439               | 416                            | 358             |
| 11/07/97    | 23.4                | 99.6               | 12.8           | 450               | 441                            | 421             |
| 11/13/97    | 24.8                | 101                | 8.1            | 442               | 437                            | 401             |
| 11/19/97    | 28.0                | 96.8               | 7.5            | 459               | 430                            | 358             |
| 11/25/97    | 25.2                | 94.1               | 6.2            | 411               | 432                            | 351             |
| 12/01/97    | 23.9                | 91.0               | 9.8            | 384               | 434                            | 378             |
| 12/07/97    | 22.5                | 91.4               | 13.3           | 451               | 465                            | 334             |
| 12/13/97    | 20.6                | 94                 | 9.1            | 472               | 496                            | 336             |
| 12/19/97    | 19.7                | 96.4               | 4.9            | 416               | 467                            | 339             |
| 12/23/97    | 18.8                | 94.4               | 6.3            | 422               | 489                            | 361             |

Table A-18 Magnesium Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | 3.2                 | BDL <sup>a</sup>   | 6.0            | 7.9               | 6.9                            | 3.5             |
| 09/26/97    | 2.4                 | BDL                | 5.1            | 8.1               | 12.8                           | 3.6             |
| 09/28/97    | 2.0                 | BDL                | 4.6            | 8.8               | 12.8                           | 3.6             |
| 09/30/97    | 2.2                 | BDL                | 4.2            | 8.8               | 12.6                           | 4.7             |
| 10/02/97    | 2.1                 | BDL                | 5.0            | 9.9               | 13.6                           | 5.8             |
| 10/04/97    | 1.6                 | BDL                | 5.3            | 10.8              | 14.6                           | 6.2             |
| 10/06/97    | 1.6                 | BDL                | 5.9            | 11.2              | 14.9                           | 7.2             |
| 10/08/97    | 1.7                 | BDL                | 6.1            | 15.8              | 16.0                           | 10.6            |
| 10/16/97    | 2.3                 | BDL                | 6.4            | 14.2              | 17.7                           | 14.1            |
| 10/20/97    | 4.9                 | BDL                | 6.7            | 15.4              | 14.6                           | 20.7            |
| 10/26/97    | 5.6                 | BDL                | 6.7            | 15.0              | 14.6                           | 23.1            |
| 11/01/97    | 6.3                 | BDL                | 7.6            | 14.5              | 12.8                           | 23.3            |
| 11/07/97    | 6.6                 | BDL                | 7.7            | 14.1              | 14.5                           | 24.3            |
| 11/13/97    | 6.4                 | BDL                | 8.0            | 15.5              | 15.4                           | 25.6            |
| 11/19/97    | 8.5                 | BDL                | 7.1            | 12.4              | 11.4                           | 23.8            |
| 11/25/97    | 7.7                 | BDL                | 6.1            | 10.5              | 14.4                           | 23.8            |
| 12/01/97    | 7.0                 | BDL                | 5.9            | 10.7              | 12.2                           | 25.2            |
| 12/07/97    | 6.3                 | BDL                | 5.1            | 10.7              | 11.6                           | 25.2            |
| 12/13/97    | 6.1                 | BDL                | 5.3            | 11.3              | 10.4                           | 25.9            |
| 12/19/97    | 5.6                 | BDL                | 4.8            | 10.1              | 10.1                           | 24.5            |
| 12/23/97    | 4.6                 | BDL                | 4.4            | 9.8               | 10.0                           | 24.0            |

<sup>a</sup> Below Detection Limit (BDL): 1.0 mg/L

Table A-19 Potassium Results in Experiment 1

| Sample Date | Cardboard<br>(mg/L) | Concrete<br>(mg/L) | Wood<br>(mg/L) | Drywall<br>(mg/L) | Drywall<br>Duplicate<br>(mg/L) | Mixed<br>(mg/L) |
|-------------|---------------------|--------------------|----------------|-------------------|--------------------------------|-----------------|
| 09/24/97    | 2.3                 | 15.8               | 4.6            | 2.5               | 2.3                            | 13.0            |
| 09/26/97    | 2.6                 | 33.3               | 7.1            | 2.7               | 3.2                            | 16.9            |
| 09/28/97    | 3.8                 | 45.7               | 9.2            | 3.0               | 3.8                            | 16.7            |
| 09/30/97    | 4.3                 | 44.7               | 10.5           | 3.3               | 4.2                            | 28.5            |
| 10/02/97    | 5.0                 | 47.4               | 14.0           | 3.6               | 4.9                            | 32.9            |
| 10/04/97    | 4.8                 | 44.8               | 16.0           | 4.0               | 5.2                            | 34.5            |
| 10/06/97    | 4.6                 | 45.1               | 17.6           | 4.2               | 5.5                            | 40.5            |
| 10/08/97    | 6.0                 | 45.4               | 17.9           | 5.6               | 5.8                            | 57.1            |
| 10/16/97    | 5.6                 | 45.1               | 18.7           | 4.6               | 6.2                            | 64.1            |
| 10/20/97    | 5.2                 | 34.4               | 19.5           | 5.1               | 5.3                            | 58.4            |
| 10/26/97    | 5.3                 | 35.2               | 19.4           | 5.1               | 5.3                            | 52.4            |
| 11/01/97    | 5.0                 | 33.1               | 20.9           | 4.7               | 4.8                            | 45.9            |
| 11/07/97    | 4.8                 | 31.0               | 19.7           | 4.5               | 5.3                            | 42.5            |
| 11/13/97    | 4.9                 | 29.7               | 19.9           | 4.2               | 4.8                            | 42.0            |
| 11/19/97    | 5.0                 | 27.6               | 18.2           | 4.0               | 4.2                            | 35.0            |
| 11/25/97    | 4.5                 | 25.1               | 15.4           | 3.6               | 5.0                            | 32.6            |
| 12/01/97    | 3.8                 | 22.0               | 15.0           | 3.2               | 4.2                            | 32.0            |
| 12/07/97    | 3.1                 | 20.8               | 12.8           | 3.1               | 4.0                            | 30.3            |
| 12/13/97    | 3.6                 | 21.5               | 13.3           | 2.4               | 3.0                            | 29.3            |
| 12/19/97    | 3.1                 | 18.9               | 12.2           | 2.4               | 2.9                            | 26.7            |
| 12/23/97    | 2.5                 | 17.2               | 11.6           | 2.4               | 2.9                            | 24.8            |

**Table A-20 Sodium Results in Experiment 1**

| <b>Sample Date</b> | <b>Cardboard<br/>(mg/L)</b> | <b>Concrete<br/>(mg/L)</b> | <b>Wood<br/>(mg/L)</b> | <b>Drywall<br/>(mg/L)</b> | <b>Drywall<br/>Duplicate<br/>(mg/L)</b> | <b>Mixed<br/>(mg/L)</b> |
|--------------------|-----------------------------|----------------------------|------------------------|---------------------------|---|-------------------------|
| 09/24/97           | 19.9                        | 12.4                       | 2.7                    | 12.5                      | 11.3                                    | 19.3                    |
| 09/26/97           | 25.0                        | 33.3                       | 1.9                    | 14.0                      | 13.5                                    | 25.3                    |
| 09/28/97           | 41.2                        | 44.6                       | 1.6                    | 14.8                      | 17.0                                    | 26.9                    |
| 09/30/97           | 48.2                        | 41.7                       | 1.5                    | 18.5                      | 20.1                                    | 40.9                    |
| 10/02/97           | 57.8                        | 41.5                       | 1.7                    | 20.9                      | 24.2                                    | 38.3                    |
| 10/04/97           | 55.4                        | 38.0                       | 1.8                    | 24.8                      | 26.4                                    | 35.9                    |
| 10/06/97           | 52.6                        | 36.3                       | 1.8                    | 27.5                      | 28.1                                    | 38.2                    |
| 10/08/97           | 70.2                        | 35.9                       | 1.8                    | 42.4                      | 29.9                                    | 45.9                    |
| 10/16/97           | 59.6                        | 34.1                       | 1.9                    | 33.5                      | 33.4                                    | 51.8                    |
| 10/20/97           | 57.3                        | 23.6                       | 2.0                    | 40.2                      | 28.6                                    | 43.1                    |
| 10/26/97           | 57.8                        | 22.7                       | 1.9                    | 38.1                      | 28.6                                    | 38.4                    |
| 11/01/97           | 55.7                        | 20.2                       | 2.4                    | 35.0                      | 24.4                                    | 34.3                    |
| 11/07/97           | 51.3                        | 17.6                       | 2.1                    | 32.9                      | 27.4                                    | 30.3                    |
| 11/13/97           | 52.1                        | 16.4                       | 2.2                    | 34.1                      | 24.9                                    | 29.6                    |
| 11/19/97           | 54.4                        | 14.3                       | 1.9                    | 27.1                      | 19.6                                    | 24.8                    |
| 11/25/97           | 47.6                        | 12.7                       | 1.6                    | 21.9                      | 24.2                                    | 23.3                    |
| 12/01/97           | 41.7                        | 10.0                       | 1.7                    | 20.6                      | 19.9                                    | 22.9                    |
| 12/07/97           | 35.8                        | 9.5                        | 1.6                    | 19.4                      | 17.8                                    | 21.6                    |
| 12/13/97           | 42.4                        | 9.6                        | 1.0                    | 17.0                      | 15.4                                    | 20.3                    |
| 12/19/97           | 38.6                        | 8.1                        | BDL <sup>a</sup>       | 15.3                      | 14.5                                    | 17.9                    |
| 12/23/97           | 32.0                        | 7.3                        | BDL                    | 14.8                      | 13.7                                    | 16.4                    |

<sup>a</sup> Below Detection Limit (BDL): 1.0 mg/L

**APPENDIX B**  
**LYSIMETER EXPERIMENT 2 - RAW DATA**

Table B-1 Leachate Volume Collected in Experiment 2 unit: ml

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | 0                | 0                |
| 01/25/99    | 0                | 0                |
| 01/28/99    | 500              | 0                |
| 01/30/99    | 1680             | 0                |
| 02/01/99    | 2640             | 0                |
| 02/03/99    | 2950             | 0                |
| 02/05/99    | 3190             | 0                |
| 02/07/99    | 3420             | 0                |
| 02/09/99    | 3490             | 0                |
| 02/11/99    | 3430             | 0                |
| 02/13/99    | 3480             | 430              |
| 02/15/99    | 3420             | 1050             |
| 02/17/99    | 3440             | 2050             |
| 02/19/99    | 3370             | 2320             |
| 02/21/99    | 3430             | 2060             |
| 02/23/99    | 3380             | 1870             |
| 02/25/99    | 3470             | 2330             |
| 02/27/99    | 3370             | 2200             |
| 03/01/99    | 3470             | 2730             |
| 03/03/99    | 3430             | 2830             |
| 03/05/99    | 3470             | 2770             |
| 03/07/99    | 3440             | 2850             |
| 03/09/99    | 3350             | 2800             |
| 03/11/99    | 2000             | 2700             |
| 03/13/99    | 3200             | 2500             |
| 03/15/99    | 3490             | 2800             |
| 03/17/99    | 3250             | 2780             |
| 03/19/99    | 3300             | 2910             |
| 03/21/99    | 3620             | 2880             |
| 03/23/99    | 3570             | 2700             |
| 03/25/99    | 3550             | 2720             |
| 03/27/99    | 3500             | 2700             |
| 03/29/99    | 3500             | 2750             |
| 03/31/99    | 3600             | 2875             |
| 04/02/99    | 3500             | 2760             |
| 04/04/99    | 3600             | 2800             |
| 04/06/99    | 3550             | 2790             |
| 04/08/99    | 3550             | 2870             |
| 04/10/99    | 3500             | 2910             |
| 04/12/99    | 3400             | 2940             |
| 04/14/99    | 3500             | 2800             |
| 04/16/99    | 3450             | 2900             |
| 04/18/99    | 3300             | 2750             |
| 04/22/99    | 3500             | 3050             |
| 04/24/99    | 3400             | 2900             |
| 04/26/99    | 3450             | 2950             |
| 04/28/99    | 3500             | 2980             |
| 04/30/99    | 3200             | 2700             |
| 05/02/99    | 3300             | 2650             |
| 05/04/99    | 3450             | 3050             |
| 05/06/99    | 3500             | 3050             |

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 05/08/99    | 3500             | 3050             |
| 05/10/99    | 3600             | 3050             |
| 05/12/99    | 3400             | 3050             |
| 05/14/99    | 3400             | 2950             |
| 05/16/99    | 3550             | 3250             |
| 05/18/99    | 3450             | 3300             |
| 05/20/99    | 3550             | 3100             |
| 05/22/99    | 3550             | 3050             |
| 05/24/99    | 3600             | 3200             |
| 05/26/99    | 3650             | 3200             |
| 05/28/99    | 3550             | 3100             |
| 05/30/99    | 3500             | 3200             |
| 06/01/99    | 3650             | 3250             |
| 06/03/99    | 3600             | 3250             |
| 06/05/99    | 3550             | 3400             |
| 06/07/99    | 3500             | 3200             |
| 06/09/99    | 3550             | 3300             |
| 06/11/99    | 3500             | 3300             |
| 06/13/99    | 3550             | 3200             |
| 06/15/99    | 3500             | 3250             |
| 06/17/99    | 3650             | 3320             |
| 06/19/99    | 3600             | 3300             |
| 06/21/99    | 3550             | 3480             |
| 06/23/99    | 3500             | 3200             |
| 06/27/99    | 3600             | 3300             |
| 06/29/99    | 3500             | 3350             |
| 07/01/99    | 3450             | 3200             |
| 07/03/99    | 3550             | 3250             |
| 07/05/99    | 3500             | 3290             |
| 07/07/99    | 3500             | 3290             |
| 07/09/99    | 3450             | 3400             |
| 07/11/99    | 3600             | 3300             |
| 07/13/99    | 3450             | 3250             |
| 07/15/99    | 3600             | 3250             |
| 07/17/99    | 3600             | 3250             |
| 07/19/99    | 3550             | 3300             |
| 07/21/99    | 3500             | 3250             |
| 07/23/99    | 3650             | 3200             |
| 07/25/99    | 3550             | 3300             |
| 07/27/99    | 3600             | 3300             |
| 07/29/99    | 3450             | 3250             |
| 07/31/99    | 3600             | 3250             |
| 08/02/99    | 3550             | 3400             |
| 08/04/99    | 3500             | 3200             |
| 08/06/99    | 3550             | 3250             |
| 08/08/99    | 3500             | 3250             |
| 08/10/99    | 3500             | 3250             |
| 08/12/99    | 3500             | 3300             |
| 08/14/99    | 3650             | 3400             |



| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 08/16/99    | 3550             | 3300             |
| 08/18/99    | 3450             | 3250             |
| 08/20/99    | 3450             | 3300             |
| 08/22/99    | 3300             | 3200             |
| 08/24/99    | 3550             | 3300             |
| 08/26/99    | 3500             | 3250             |
| 08/28/99    | 3550             | 3400             |
| 08/30/99    | 3500             | 3200             |
| 09/01/99    | 3550             | 3250             |
| 09/03/99    | 3500             | 3050             |
| 09/05/99    | 3400             | 2900             |
| 09/07/99    | 3500             | 3200             |
| 09/09/99    | 3500             | 3250             |
| 09/11/99    | 3650             | 3250             |
| 09/13/99    | 3550             | 3400             |
| 09/15/99    | 3600             | 3300             |
| 09/18/99    | 5250             | 4950             |
| 09/20/99    | 3600             | 3250             |
| 09/22/99    | 3500             | 3250             |
| 09/24/99    | 3500             | 3300             |
| 09/26/99    | 3400             | 3250             |
| 09/28/99    | 3450             | 3300             |
| 09/30/99    | 3400             | 3400             |
| 10/02/99    | 3550             | 3300             |
| 10/05/99    | 5250             | 4900             |
| 10/07/99    | 3600             | 3250             |
| 10/09/99    | 3500             | 3150             |
| 10/11/99    | 3400             | 3200             |
| 10/13/99    | 3500             | 3300             |
| 10/15/99    | 3500             | 3250             |
| 10/17/99    | 3600             | 3250             |
| 10/19/99    | 3550             | 3400             |
| 10/21/99    | 3550             | 3300             |
| 10/23/99    | 3600             | 3400             |
| 10/25/99    | 3600             | 3300             |
| 10/27/99    | 3550             | 3250             |
| 10/29/99    | 3500             | 3200             |
| 10/31/99    | 3500             | 3250             |
| 11/02/99    | 3600             | 3250             |
| 11/04/99    | 3550             | 3400             |
| 11/06/99    | 3600             | 3400             |
| 11/09/99    | 5300             | 5000             |
| 11/11/99    | 3550             | 3250             |
| 11/13/99    | 3600             | 3300             |
| 11/15/99    | 3500             | 3400             |
| 11/17/99    | 3550             | 3300             |
| 11/19/99    | 3450             | 3250             |
| 11/21/99    | 3500             | 3200             |
| 11/23/99    | 3500             | 3350             |
| 11/25/99    | 3600             | 3250             |
| 11/27/99    | 3550             | 3400             |

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 11/29/99    | 3500             | 3200             |
| 12/01/99    | 3500             | 3250             |
| 12/03/99    | 3500             | 3200             |
| 12/05/99    | 3500             | 3250             |
| 12/07/99    | 3600             | 3300             |
| 12/09/99    | 3550             | 3400             |
| 12/11/99    | 3500             | 3200             |
| 12/13/99    | 3500             | 3250             |
| 12/15/99    | 3600             | 3250             |
| 12/17/99    | 3550             | 3400             |
| 12/19/99    | 3600             | 3250             |
| 12/21/99    | 3550             | 3400             |
| 12/23/99    | 3650             | 3350             |
| 12/25/99    | 3600             | 3300             |
| 12/27/99    | 3450             | 3250             |
| 12/29/99    | 3500             | 3200             |
| 12/31/99    | 3500             | 3250             |
| 01/03/00    | 5300             | 5150             |
| 01/05/00    | 3600             | 3300             |
| 01/07/00    | 3450             | 3250             |
| 01/09/00    | 3600             | 3350             |
| 01/11/00    | 3550             | 3400             |
| 01/13/00    | 3500             | 3300             |
| 01/15/00    | 3550             | 3400             |
| 01/17/00    | 3600             | 3300             |
| 01/19/00    | 3450             | 3250             |
| 01/21/00    | 3600             | 3250             |
| 01/23/00    | 3600             | 3300             |

Table B-2 pH Results in Experiment 2

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/28/99    | 7.09             | NS <sup>a</sup>  |
| 01/30/99    | 7.10             | NS               |
| 02/01/99    | 6.74             | NS               |
| 02/03/99    | 6.46             | NS               |
| 02/05/99    | 6.44             | NS               |
| 02/07/99    | 6.42             | NS               |
| 02/09/99    | 6.43             | NS               |
| 02/11/99    | 6.30             | NS               |
| 02/13/99    | 6.23             | 6.97             |
| 02/15/99    | 6.06             | 6.99             |
| 02/17/99    | 5.94             | 6.96             |
| 02/19/99    | 5.88             | 7.00             |
| 02/21/99    | 5.86             | 6.93             |
| 02/23/99    | 5.90             | 6.95             |
| 02/25/99    | 5.94             | 6.90             |
| 02/27/99    | 5.97             | 6.82             |
| 03/01/99    | 6.20             | 6.80             |
| 03/03/99    | 6.22             | 6.78             |
| 03/05/99    | 6.28             | 6.63             |
| 03/07/99    | 6.42             | 6.63             |
| 03/09/99    | 6.46             | 6.58             |
| 03/11/99    | 6.62             | 6.69             |
| 03/13/99    | 6.41             | 6.51             |
| 03/15/99    | 6.52             | 6.54             |
| 03/17/99    | 6.47             | 6.57             |
| 03/19/99    | 6.58             | 6.70             |
| 03/21/99    | 6.57             | 6.55             |
| 03/23/99    | 6.59             | 6.59             |
| 03/25/99    | 6.56             | 6.51             |
| 03/27/99    | 6.57             | 6.67             |
| 03/29/99    | 6.58             | 6.72             |
| 03/31/99    | 6.56             | 6.68             |
| 04/02/99    | 6.58             | 6.68             |
| 04/04/99    | 6.57             | 6.65             |
| 04/06/99    | 6.63             | 6.67             |
| 04/08/99    | 6.64             | 6.71             |
| 04/10/99    | 6.59             | 6.69             |
| 04/12/99    | 6.71             | 6.75             |
| 04/14/99    | 6.58             | 6.62             |
| 04/16/99    | 6.68             | 6.71             |
| 04/18/99    | 6.72             | 6.70             |
| 04/20/99    | 6.70             | 6.61             |
| 04/22/99    | 6.67             | 6.65             |
| 04/26/99    | 6.63             | 6.55             |
| 04/28/99    | 6.64             | 6.62             |
| 04/30/99    | 6.70             | 6.71             |
| 05/02/99    | 6.67             | 6.66             |
| 05/04/99    | 6.56             | 6.63             |
| 05/06/99    | 6.57             | 6.62             |
| 05/08/99    | 6.57             | 6.68             |
| 05/10/99    | 6.62             | 6.67             |

<sup>a</sup> Not Sampled

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 05/12/99    | 6.63             | 6.69             |
| 05/14/99    | 6.60             | 6.65             |
| 05/18/99    | 6.61             | 6.65             |
| 05/20/99    | 6.53             | 6.67             |
| 05/22/99    | 6.56             | 6.67             |
| 05/24/99    | 6.53             | 6.67             |
| 05/26/99    | 6.53             | 6.65             |
| 05/28/99    | 6.47             | 6.63             |
| 05/30/99    | 6.53             | 6.70             |
| 06/01/99    | 6.53             | 6.63             |
| 06/03/99    | 6.51             | 6.63             |
| 06/05/99    | 6.50             | 6.65             |
| 06/07/99    | 6.53             | 6.61             |
| 06/09/99    | 6.51             | 6.71             |
| 06/11/99    | 6.55             | 6.68             |
| 06/13/99    | 6.48             | 6.64             |
| 06/15/99    | 6.47             | 6.64             |
| 06/17/99    | 6.52             | 6.67             |
| 06/19/99    | 6.55             | 6.71             |
| 06/21/99    | 6.46             | 6.67             |
| 06/23/99    | 6.50             | 6.68             |
| 06/27/99    | 6.50             | 6.68             |
| 06/29/99    | 6.53             | 6.66             |
| 07/01/99    | 6.47             | 6.70             |
| 07/03/99    | 6.49             | 6.70             |
| 07/05/99    | 6.44             | 6.66             |
| 07/07/99    | 6.39             | 6.70             |
| 07/09/99    | 6.49             | 6.69             |
| 07/11/99    | 6.46             | 6.66             |
| 07/13/99    | 6.60             | 6.75             |
| 07/15/99    | 6.47             | 6.65             |
| 07/17/99    | 6.47             | 6.76             |
| 07/19/99    | 6.50             | 6.73             |
| 07/21/99    | 6.50             | 6.75             |
| 07/23/99    | 6.51             | 6.74             |
| 07/25/99    | 6.46             | 6.75             |
| 07/29/99    | 6.58             | 6.71             |
| 08/02/99    | 6.51             | 6.80             |
| 08/04/00    | 6.52             | 6.69             |
| 08/06/00    | 6.44             | 6.65             |
| 08/10/00    | 6.41             | 6.62             |
| 08/23/00    | 6.50             | 6.61             |
| 09/20/00    | 6.45             | 6.56             |
| 10/11/00    | 6.45             | 6.57             |
| 10/27/00    | 6.47             | 6.55             |
| 11/23/00    | 6.61             | 6.77             |
| 12/13/00    | 6.47             | 6.72             |
| 01/07/00    | 6.61             | 6.74             |
| 01/23/00    | 6.58             | 6.70             |

Table B-3 DO Results in Experiment 2

unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/28/99    | 4.72             | NS <sup>a</sup>  |
| 01/30/99    | 2.95             | NS               |
| 02/01/99    | 1.72             | NS               |
| 02/03/99    | 0.88             | NS               |
| 02/05/99    | 0.79             | NS               |
| 02/07/99    | 0.84             | NS               |
| 02/09/99    | 0.82             | NS               |
| 02/11/99    | 0.80             | NS               |
| 02/13/99    | 0.96             | 4.59             |
| 02/15/99    | 0.84             | 2.22             |
| 02/17/99    | 0.78             | 1.77             |
| 02/19/99    | 0.70             | 1.34             |
| 02/21/99    | 0.78             | 0.98             |
| 02/23/99    | 0.88             | 1.16             |
| 02/25/99    | 1.02             | 1.15             |
| 02/27/99    | 1.16             | 1.14             |
| 03/01/99    | 1.11             | 1.35             |
| 03/03/99    | 1.46             | 1.37             |
| 03/05/99    | 1.59             | 1.76             |
| 03/07/99    | 0.89             | 0.88             |
| 03/09/99    | 1.05             | 0.95             |
| 03/11/99    | 1.30             | 1.53             |
| 03/13/99    | 1.39             | 1.33             |
| 03/15/99    | 0.52             | 0.98             |
| 03/17/99    | 0.88             | 0.88             |
| 03/19/99    | 1.20             | 0.86             |
| 03/21/99    | 1.52             | 0.84             |
| 03/23/99    | 0.99             | 0.87             |
| 03/25/99    | 0.98             | 0.92             |
| 03/27/99    | 1.02             | 0.79             |
| 03/29/99    | 1.10             | 0.78             |
| 03/31/99    | 1.02             | 0.72             |
| 04/02/99    | 1.00             | 0.79             |
| 04/04/99    | 1.09             | 0.95             |
| 04/06/99    | 1.10             | 0.81             |
| 04/08/99    | 0.91             | 0.64             |
| 04/10/99    | 0.94             | 0.78             |
| 04/12/99    | 0.87             | 0.86             |
| 04/14/99    | 0.80             | 0.76             |
| 04/16/99    | 0.90             | 0.85             |
| 04/18/99    | 0.95             | 0.74             |
| 04/20/99    | 1.00             | 0.92             |
| 04/22/99    | 0.97             | 1.06             |
| 04/24/99    | 0.99             | 0.85             |
| 04/26/99    | 1.00             | 0.73             |
| 04/28/99    | 0.99             | 0.81             |
| 04/30/99    | 0.43             | 0.33             |
| 05/02/99    | 1.10             | 0.87             |
| 05/04/99    | 0.97             | 0.95             |
| 05/06/99    | 0.82             | 1.00             |
| 05/10/99    | 0.75             | 0.71             |

<sup>a</sup> Not Sampled

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 05/12/99    | 0.79             | 0.85             |
| 05/14/99    | 0.96             | 0.95             |
| 05/16/99    | 0.97             | 1.01             |
| 05/18/99    | 0.97             | 1.06             |
| 05/20/99    | 1.01             | 0.91             |
| 05/22/99    | 0.91             | 0.97             |
| 05/24/99    | 0.88             | 0.92             |
| 05/26/99    | 0.90             | 0.92             |
| 05/28/99    | 0.93             | 0.92             |
| 05/30/99    | 0.95             | 0.91             |
| 06/01/99    | 0.87             | 0.92             |
| 06/03/99    | 0.83             | 0.90             |
| 06/05/99    | 0.87             | 1.12             |
| 06/07/99    | 0.85             | 1.05             |
| 06/09/99    | 0.77             | 1.02             |
| 06/11/99    | 0.98             | 0.98             |
| 06/13/99    | 0.87             | 0.85             |
| 06/15/99    | 1.04             | 0.94             |
| 06/17/99    | 0.95             | 1.11             |
| 06/19/99    | 0.88             | 0.95             |
| 06/21/99    | 0.85             | 1.04             |
| 06/23/99    | 0.85             | 1.23             |
| 06/27/99    | 0.77             | 1.17             |
| 06/29/99    | 0.83             | 1.02             |
| 07/01/99    | 0.95             | 1.13             |
| 07/03/99    | 0.67             | 0.94             |
| 07/05/99    | 0.90             | 1.05             |
| 07/07/99    | 1.10             | 1.00             |
| 07/09/99    | 1.06             | 0.93             |
| 07/11/99    | 0.97             | 1.26             |
| 07/13/99    | 0.93             | 1.34             |
| 07/15/99    | 1.03             | 1.01             |
| 07/17/99    | 1.13             | 1.02             |
| 07/19/99    | 0.93             | 0.92             |
| 07/21/99    | 1.13             | 1.02             |
| 07/25/99    | 0.83             | 1.04             |
| 07/27/99    | 1.22             | 1.31             |
| 07/29/99    | 0.88             | 1.07             |
| 08/02/99    | 1.12             | 1.18             |
| 08/04/99    | 1.03             | 1.13             |
| 08/06/99    | 0.85             | 1.14             |
| 08/10/99    | 1.13             | 1.38             |
| 08/23/99    | 1.40             | 1.62             |
| 09/20/99    | 1.36             | 1.49             |
| 10/11/99    | 1.12             | 1.35             |
| 10/27/99    | 1.26             | 1.19             |
| 11/23/99    | 1.50             | 1.10             |
| 12/13/99    | 1.47             | 0.99             |
| 01/07/00    | 1.48             | 1.24             |
| 01/23/00    | 1.47             | 1.00             |

Table B-4 ORP Results in Experiment 2 unit: mV

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/28/99    | 205              | NS <sup>a</sup>  |
| 01/30/99    | 174              | NS               |
| 02/01/99    | 64.5             | NS               |
| 02/03/99    | -10.3            | NS               |
| 02/05/99    | -50.0            | NS               |
| 02/07/99    | -81.6            | NS               |
| 02/09/99    | -32.0            | NS               |
| 02/11/99    | -92.0            | 168              |
| 02/13/99    | -135             | 120              |
| 02/15/99    | -172             | 97.8             |
| 02/17/99    | -216             | 50.8             |
| 02/19/99    | -221             | 50.5             |
| 02/21/99    | -215             | 25.7             |
| 02/23/99    | -232             | -108             |
| 02/25/99    | -237             | -148             |
| 02/27/99    | -255             | -95.4            |
| 03/01/99    | -255             | -138             |
| 03/03/99    | -271             | -159             |
| 03/05/99    | -287             | -180             |
| 03/07/99    | -330             | -194             |
| 03/09/99    | -350             | -215             |
| 03/11/99    | -354             | -259             |
| 03/13/99    | -358             | -303             |
| 03/15/99    | -344             | -290             |
| 03/17/99    | -315             | -286             |
| 03/19/99    | -329             | -292             |
| 03/21/99    | -323             | -297             |
| 03/23/99    | -331             | -318             |
| 03/25/99    | -334             | -337             |
| 03/27/99    | -335             | -356             |
| 03/29/99    | -342             | -359             |
| 03/31/99    | -345             | -372             |
| 04/02/99    | -342             | -360             |
| 04/04/99    | -341             | -355             |
| 04/06/99    | -349             | -344             |
| 04/08/99    | -360             | -333             |
| 04/10/99    | -336             | -328             |
| 04/12/99    | -342             | -350             |
| 04/14/99    | -330             | -324             |
| 04/16/99    | -330             | -339             |
| 04/18/99    | -338             | -355             |
| 04/20/99    | -336             | -354             |
| 04/22/99    | -334             | -357             |
| 04/24/99    | -333             | -351             |
| 04/26/99    | -360             | -354             |
| 04/28/99    | -340             | -354             |
| 04/30/99    | -313             | -336             |
| 05/02/99    | -334             | -352             |
| 05/04/99    | -321             | -352             |
| 05/06/99    | -318             | -338             |
| 05/08/99    | -324             | -351             |

<sup>a</sup> Not Sampled

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 05/10/99    | -330             | -350             |
| 05/12/99    | -335             | -365             |
| 05/14/99    | -330             | -356             |
| 05/16/99    | -330             | -362             |
| 05/18/99    | -304             | -355             |
| 05/20/99    | -314             | -380             |
| 05/22/99    | -317             | -360             |
| 05/24/99    | -320             | -360             |
| 05/26/99    | -314             | -375             |
| 05/28/99    | -313             | -362             |
| 05/30/99    | -313             | -359             |
| 06/01/99    | -310             | -350             |
| 06/03/99    | -314             | -339             |
| 06/05/99    | -306             | -347             |
| 06/07/99    | -320             | -364             |
| 06/09/99    | -312             | -363             |
| 06/11/99    | -311             | -364             |
| 06/13/99    | -306             | -358             |
| 06/15/99    | -265             | -337             |
| 06/17/99    | -341             | -366             |
| 06/19/99    | -302             | -335             |
| 06/21/99    | -293             | -342             |
| 06/23/99    | -295             | -342             |
| 06/27/99    | -283             | -328             |
| 06/29/99    | -273             | -349             |
| 07/01/99    | -280             | -340             |
| 07/03/99    | -282             | -333             |
| 07/05/99    | -286             | -349             |
| 07/07/99    | -293             | -340             |
| 07/09/99    | -292             | -332             |
| 07/11/99    | -318             | -343             |
| 07/13/99    | -304             | -331             |
| 07/15/99    | -286             | -349             |
| 07/17/99    | -293             | -340             |
| 07/19/99    | -292             | -333             |
| 07/21/99    | -318             | -343             |
| 07/23/99    | -304             | -331             |
| 07/25/99    | -305             | -325             |
| 07/27/99    | -312             | -345             |
| 07/29/99    | -277             | -320             |
| 08/02/99    | -297             | -330             |
| 08/04/99    | -309             | -324             |
| 08/06/99    | -278             | -313             |
| 08/10/99    | -315             | -347             |
| 08/23/99    | -310             | -344             |
| 09/20/99    | -309             | -327             |
| 10/11/99    | -309             | -322             |
| 10/27/99    | -316             | -320             |
| 11/23/99    | -303             | -345             |
| 12/13/99    | -269             | -336             |
| 01/07/00    | -281             | -320             |
| 01/23/00    | -269             | -312             |



Table B-5 Specific Conductance Results in Experiment 2 unit:  $\mu\text{S}/\text{cm}$ 

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/28/99    | 1506             | NS <sup>a</sup>  |
| 01/30/99    | 1776             | NS               |
| 02/01/99    | 1786             | NS               |
| 02/03/99    | 1677             | NS               |
| 02/05/99    | 1611             | NS               |
| 02/07/99    | 1578             | NS               |
| 02/09/99    | 1606             | NS               |
| 02/11/99    | 1667             | NS               |
| 02/13/99    | 1728             | 2410             |
| 02/15/99    | 1850             | 3000             |
| 02/17/99    | 1909             | 2880             |
| 02/19/99    | 2010             | 2830             |
| 02/21/99    | 2110             | 2920             |
| 02/23/99    | 2030             | 2860             |
| 02/25/99    | 2120             | 2760             |
| 02/27/99    | 2060             | 2950             |
| 03/01/99    | 1932             | 2990             |
| 03/03/99    | 1836             | 2810             |
| 03/05/99    | 1864             | 2830             |
| 03/07/99    | 1990             | 2920             |
| 03/09/99    | 1903             | 2940             |
| 03/11/99    | 1890             | 3010             |
| 03/13/99    | 2040             | 3040             |
| 03/15/99    | 1944             | 3170             |
| 03/17/99    | 1763             | 3110             |
| 03/19/99    | 1703             | 3220             |
| 03/21/99    | 1718             | 3170             |
| 03/23/99    | 1732             | 3220             |
| 03/25/99    | 1653             | 3450             |
| 03/27/99    | 1580             | 3440             |
| 03/29/99    | 1596             | 3450             |
| 03/31/99    | 1597             | 3520             |
| 04/02/99    | 1610             | 3460             |
| 04/04/99    | 1613             | 3280             |
| 04/06/99    | 1603             | 3090             |
| 04/08/99    | 1507             | 3060             |
| 04/10/99    | 1540             | 3020             |
| 04/12/99    | 1536             | 2940             |
| 04/14/99    | 1530             | 2940             |
| 04/16/99    | 1446             | 2830             |
| 04/18/99    | 1390             | 2730             |
| 04/20/99    | 1378             | 2750             |
| 04/22/99    | 1308             | 2760             |
| 04/24/99    | 1281             | 2760             |
| 04/26/99    | 1253             | 2780             |
| 04/28/99    | 1277             | 2730             |
| 04/30/99    | 1235             | 2770             |
| 05/02/99    | 1196             | 2790             |
| 05/04/99    | 1190             | 2960             |
| 05/06/99    | 1250             | 3140             |
| 05/08/99    | 1231             | 2990             |

<sup>a</sup> Not Sampled

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 05/10/99    | 1190             | 3010             |
| 05/12/99    | 1188             | 2760             |
| 05/14/99    | 1193             | 2750             |
| 05/16/99    | 1243             | 2705             |
| 05/18/99    | 1292             | 2660             |
| 05/20/99    | 1146             | 2610             |
| 05/22/99    | 1158             | 2570             |
| 05/24/99    | 1172             | 2470             |
| 05/26/99    | 1252             | 2540             |
| 05/28/99    | 1261             | 2510             |
| 05/30/99    | 1270             | 2480             |
| 06/01/99    | 1239             | 2360             |
| 06/03/99    | 1204             | 2350             |
| 06/05/99    | 1171             | 2290             |
| 06/07/99    | 1150             | 2190             |
| 06/09/99    | 1101             | 2240             |
| 06/11/99    | 1073             | 2360             |
| 06/13/99    | 1036             | 2380             |
| 06/15/99    | 1033             | 2400             |
| 06/17/99    | 1022             | 2400             |
| 06/19/99    | 1075             | 2450             |
| 06/21/99    | 1095             | 2390             |
| 06/23/99    | 1085             | 2450             |
| 06/27/99    | 1222             | 2600             |
| 06/29/99    | 1135             | 2860             |
| 07/01/99    | 1085             | 3020             |
| 07/03/99    | 1074             | 3000             |
| 07/05/99    | 1092             | 3050             |
| 07/07/99    | 1113             | 3010             |
| 07/09/99    | 1097             | 2910             |
| 07/11/99    | 1101             | 2800             |
| 07/13/99    | 1107             | 2790             |
| 07/15/99    | 1083             | 2640             |
| 07/17/99    | 1092             | 2660             |
| 07/19/99    | 1137             | 2680             |
| 07/21/99    | 1149             | 2690             |
| 07/23/99    | 1149             | 2690             |
| 07/25/99    | 1127             | 2660             |
| 07/27/99    | 1145             | 2620             |
| 07/29/99    | 1163             | 2540             |
| 08/02/99    | 1160             | 2440             |
| 08/04/99    | 1122             | 2400             |
| 08/06/99    | 1065             | 2340             |
| 08/10/99    | 1022             | 2295             |
| 08/23/99    | 978              | 2250             |
| 09/20/99    | 1130             | 2510             |
| 10/11/99    | 1105             | 2610             |
| 10/27/99    | 1227             | 2770             |
| 11/23/99    | 1009             | 2610             |
| 12/13/99    | 980              | 2600             |
| 01/07/00    | 1057             | 2570             |
| 01/23/00    | 1071             | 2420             |

Table B-6 TDS Results in Experiment 2

unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 02/01/99    | 2060             | NS <sup>a</sup>  |
| 02/03/99    | 1760             | NS               |
| 02/05/99    | 1420             | NS               |
| 02/09/99    | 1340             | NS               |
| 02/11/99    | 1280             | NS               |
| 02/13/99    | 1380             | NS               |
| 02/15/99    | 1440             | 2620             |
| 02/17/99    | 1560             | 2900             |
| 02/19/99    | 2060             | 3000             |
| 02/21/99    | 2060             | 2820             |
| 02/25/99    | 1960             | 2340             |
| 02/27/99    | 2040             | 2660             |
| 03/01/99    | 1880             | 2540             |
| 03/03/99    | 1740             | 2540             |
| 03/07/99    | 1600             | 2540             |
| 03/09/99    | 1700             | 2300             |
| 03/11/99    | 1400             | 2300             |
| 03/13/99    | 1660             | 2580             |
| 03/19/99    | 1200             | 2640             |
| 03/23/99    | 1250             | 2820             |
| 03/25/99    | 1100             | 2890             |
| 03/31/99    | 1090             | 2890             |
| 04/02/99    | 1300             | 2980             |
| 04/06/99    | 1290             | 2610             |
| 04/12/99    | 1160             | 2290             |
| 04/18/99    | 1170             | 2400             |
| 04/24/99    | 1140             | 2210             |
| 04/30/99    | 740              | 2080             |
| 05/06/99    | 1140             | 2140             |
| 05/12/99    | 950              | 2200             |
| 05/18/99    | 1090             | 2070             |
| 05/24/99    | 910              | 2020             |
| 05/30/99    | 1000             | 1950             |
| 06/05/99    | 880              | 1640             |
| 06/11/99    | 770              | 1700             |
| 07/17/99    | 750              | 1820             |
| 06/29/99    | 860              | 2410             |
| 07/03/99    | 760              | 2300             |
| 07/09/99    | 760              | 2250             |
| 07/15/99    | 770              | 2050             |
| 07/21/99    | 870              | 2130             |
| 07/27/99    | 880              | 2120             |
| 08/10/99    | 840              | 1700             |
| 08/23/99    | 770              | 1910             |
| 09/20/99    | 700              | 2120             |
| 10/11/99    | 840              | 2120             |
| 10/27/99    | 730              | 1970             |
| 11/23/99    | 710              | 1930             |
| 12/13/99    | 650              | 1920             |
| 01/07/00    | 550              | 1950             |
| 01/23/00    | 770              | 1900             |

<sup>a</sup> Not Sampled

Table B-7 Alkalinity Results in Experiment 2

unit: mg/L as  $\text{CaCO}_3$ 

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 140              | NS <sup>a</sup>  |
| 02/01/99    | 130              | NS               |
| 02/03/99    | 180              | NS               |
| 02/05/99    | 220              | NS               |
| 02/07/99    | 250              | NS               |
| 02/09/99    | 290              | NS               |
| 02/11/99    | 390              | NS               |
| 02/13/99    | 370              | 140              |
| 02/15/99    | 420              | 70               |
| 02/17/99    | 480              | 90               |
| 02/19/99    | 520              | 180              |
| 02/21/99    | 560              | 150              |
| 02/23/99    | 560              | 260              |
| 02/25/99    | 690              | 230              |
| 02/27/99    | 640              | 270              |
| 03/01/99    | 640              | 320              |
| 03/03/99    | 720              | 350              |
| 03/07/99    | 800              | 400              |
| 03/11/99    | 790              | 430              |
| 03/13/99    | 780              | 530              |
| 03/19/99    | 850              | 810              |
| 03/25/99    | 790              | 1000             |
| 03/31/99    | 780              | 1140             |
| 04/06/99    | 750              | 1200             |
| 04/12/99    | 890              | 1270             |
| 04/18/99    | 800              | 1250             |
| 04/24/99    | 680              | 1280             |
| 04/30/99    | 650              | 1200             |
| 05/06/99    | 600              | 1280             |
| 05/12/99    | 600              | 1160             |
| 05/18/99    | 650              | 1160             |
| 05/24/99    | 550              | 1160             |
| 05/30/99    | 560              | 1190             |
| 06/05/99    | 600              | 1110             |
| 06/11/99    | 580              | 1200             |
| 06/17/99    | 560              | 1170             |
| 06/29/99    | 590              | 1050             |
| 07/03/99    | 530              | 1180             |
| 07/09/99    | 530              | 1130             |
| 07/15/99    | 540              | 1190             |
| 07/21/99    | 540              | 1190             |
| 07/27/99    | 560              | 1150             |
| 08/10/99    | 490              | 1050             |
| 09/20/99    | 500              | 1000             |
| 10/11/99    | 450              | 1000             |
| 10/27/99    | 450              | 1000             |
| 11/23/99    | 430              | 960              |
| 12/13/99    | 410              | 950              |
| 01/07/00    | 430              | 940              |
| 01/23/00    | 400              | 850              |

<sup>a</sup> Not Sampled

Table B-8 Sulfide Results in Experiment 2

| Sample Date | Single Lysimeter<br>(mg/L as S <sup>2-</sup> ) | Serial Lysimeter<br>(mg/L as S <sup>2-</sup> ) |
|-------------|--|--|
| 01/23/99    | NS <sup>a</sup>                                | NS   |
| 01/30/99    | 0.01   | NS   |
| 02/05/99    | 0.02   | NS   |
| 02/11/99    | 0.10   | NS   |
| 02/17/99    | 1.05   | 0.02   |
| 02/23/99    | 5.10   | 0.02   |
| 02/25/99    | 5.87   | 0.02   |
| 03/01/99    | 10.40  | 0.02   |
| 03/07/99    | 14.44  | 0.20   |
| 03/13/99    | 17.96  | 9.12   |
| 03/19/99    | 12.40  | 8.25   |
| 03/25/99    | 20.00  | 15.25  |
| 03/29/99    | 24.50  | 18.35  |
| 03/31/99    | 20.40  | 21.00  |
| 04/06/99    | 29.25  | 28.75  |
| 04/08/99    | 30.00  | 26.80  |
| 04/10/99    | 28.00  | 27.25  |
| 04/12/99    | 27.75  | 29.75  |
| 04/18/99    | 24.50  | 24.75  |
| 04/24/99    | 21.00  | 24.75  |
| 04/30/99    | 18.50  | 29.25  |
| 05/06/99    | 14.50  | 37.40  |
| 05/12/99    | 12.60  | 36.50  |
| 05/18/99    | 8.80   | 27.70  |
| 05/24/99    | 12.00  | 36.70  |
| 05/30/99    | 7.50   | 32.20  |
| 06/05/99    | 9.60   | 26.70  |
| 06/11/99    | 8.65   | 34.10  |
| 06/17/99    | 8.45   | 37.10  |
| 06/29/99    | 7.50   | 20.10  |
| 07/03/99    | 7.90   | 33.50  |
| 07/09/99    | 7.45   | 28.30  |
| 07/15/99    | 8.20   | 28.30  |
| 07/21/99    | 6.90   | 16.60  |
| 07/27/99    | 7.60   | 21.00  |
| 08/10/99    | 7.85   | 25.40  |
| 8/23/99     | 5.65   | 20.50  |
| 09/20/99    | 9.85   | 20.40  |
| 10/11/99    | 6.85   | 16.60  |
| 10/27/99    | 5.95   | 20.90  |
| 11/23/99    | 6.90   | 22.80  |
| 12/13/99    | 6.00   | 20.60  |
| 01/07/00    | 6.05   | 18.40  |
| 01/23/99    | 5.40   | 19.30  |

<sup>a</sup> Not Sampled

Table B-9 NPOC Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 288              | NS               |
| 02/01/99    | 234              | NS               |
| 02/03/99    | 161              | NS               |
| 02/05/99    | 90.1             | NS               |
| 02/07/99    | 130              | NS               |
| 02/09/99    | 79.7             | NS               |
| 02/11/99    | 214              | NS               |
| 02/13/99    | 285              | NS               |
| 02/15/99    | 315              | NS               |
| 02/17/99    | 432              | 625              |
| 02/19/99    | 505              | 475              |
| 02/21/99    | 547              | 450              |
| 02/23/99    | 517              | 350              |
| 02/25/99    | 506              | 275              |
| 02/27/99    | 414              | 250              |
| 03/01/99    | 381              | 275              |
| 03/03/99    | 366              | 225              |
| 03/07/99    | 352              | 241              |
| 03/13/99    | 313              | 122              |
| 03/19/99    | 176              | 144              |
| 03/25/99    | 167              | 207              |
| 03/31/99    | 146              | 194              |
| 04/06/99    | 225              | 180              |
| 04/12/99    | 156              | 86.2             |
| 04/18/99    | 107              | 76.7             |
| 04/24/99    | 65.3             | 97.1             |
| 04/30/99    | 55.3             | 112              |
| 05/06/99    | 44.0             | 141              |
| 05/12/99    | 35.7             | 76.7             |
| 05/18/99    | 48.9             | 98.7             |
| 05/24/99    | 30.4             | 78.4             |
| 05/30/99    | 31.2             | 43.6             |
| 06/05/99    | 39.2             | 48.1             |
| 06/11/99    | 46.3             | 57.3             |
| 06/17/99    | 25.7             | 42.8             |
| 06/29/99    | 26.2             | 67.1             |
| 07/03/99    | 20.6             | 71.3             |
| 07/09/99    | 17.9             | 48.6             |
| 07/15/99    | 18.9             | 43.3             |
| 07/21/99    | 24.6             | 30.7             |
| 07/27/99    | 18.1             | 26.9             |
| 08/10/99    | 19.3             | 48.9             |
| 09/20/99    | 22.2             | 37.4             |
| 10/11/99    | 20.4             | 30.0             |
| 10/27/99    | 23.0             | 19.4             |
| 11/23/99    | 20.4             | 23.3             |
| 12/13/99    | 13.8             | 37.0             |
| 01/07/00    | 13.6             | 31.0             |
| 01/23/00    | 15.5             | 22.7             |

<sup>a</sup> Not Sampled

Table B-10 COD Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 850              | NS <sup>a</sup>  |
| 02/01/99    | 680              | NS               |
| 02/03/99    | 500              | NS               |
| 02/05/99    | 330              | NS               |
| 02/07/99    | 1050             | NS               |
| 02/09/99    | 480              | NS               |
| 02/11/99    | 830              | NS               |
| 02/13/99    | 1100             | 630              |
| 02/15/99    | 1350             | 480              |
| 02/17/99    | 1450             | 450              |
| 02/19/99    | 1550             | 350              |
| 02/21/99    | 1700             | 280              |
| 02/23/99    | 1400             | 250              |
| 02/25/99    | 1500             | 280              |
| 02/27/99    | 1300             | 250              |
| 03/01/99    | 1300             | 200              |
| 03/03/99    | 1170             | 230              |
| 03/07/99    | 1040             | 240              |
| 03/13/99    | 1050             | 470              |
| 03/19/99    | 620              | 440              |
| 03/25/99    | 490              | 600              |
| 03/31/99    | 430              | 580              |
| 04/06/99    | 390              | 550              |
| 04/12/99    | 280              | 510              |
| 04/18/99    | 230              | 410              |
| 04/24/99    | 310              | 410              |
| 04/30/99    | 260              | 410              |
| 05/06/99    | 210              | 470              |
| 05/12/99    | 240              | 380              |
| 05/18/99    | 310              | 500              |
| 05/24/99    | 240              | 410              |
| 05/30/99    | 180              | 210              |
| 06/05/99    | 110              | 170              |
| 06/11/99    | 99.0             | 220              |
| 06/17/99    | 84.0             | 200              |
| 06/29/99    | 92.0             | 250              |
| 07/03/99    | 71.0             | 250              |
| 07/09/99    | 72.0             | 190              |
| 07/15/99    | 76.0             | 140              |
| 07/21/99    | 77.0             | 150              |
| 07/27/99    | 77.0             | 150              |
| 08/10/99    | 80.0             | 150              |
| 08/23/99    | 87.0             | 140              |
| 09/20/99    | 93.0             | 130              |
| 10/11/99    | 68.0             | 110              |
| 10/27/99    | 64.0             | 140              |
| 11/23/99    | 54.0             | 110              |
| 12/13/99    | 50.0             | 110              |
| 01/07/00    | 56.0             | 93.0             |
| 01/23/99    | 44.0             | 90.0             |

<sup>a</sup> Not Sampled

Table B-11 Sulfate Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 1069             | NS <sup>a</sup>  |
| 02/01/99    | 1364             | NS               |
| 02/03/99    | 559              | NS               |
| 02/05/99    | 491              | NS               |
| 02/07/99    | 527              | NS               |
| 02/09/99    | 502              | NS               |
| 02/11/99    | 483              | NS               |
| 02/13/99    | 425              | 1124             |
| 02/15/99    | 394              | 1523             |
| 02/17/99    | 353              | 1464             |
| 02/19/99    | 297              | 1427             |
| 02/21/99    | 281              | 1389             |
| 02/23/99    | 211              | 1569             |
| 02/25/99    | 247              | 1426             |
| 02/27/99    | 194              | 1417             |
| 03/01/99    | 170              | 1411             |
| 03/07/99    | 88.9             | 1284             |
| 03/13/99    | 68.3             | 1162             |
| 03/19/99    | 57.3             | 1062             |
| 03/23/99    | 33.7             | 982              |
| 03/25/99    | 66.5             | 901              |
| 03/29/99    | 47.7             | 838              |
| 03/31/99    | 29.0             | 825              |
| 04/06/99    | 42.9             | 535              |
| 04/12/99    | 38.8             | 476              |
| 04/18/99    | 56.9             | 455              |
| 04/24/99    | 45.3             | 551              |
| 04/26/99    | 33.7             | 515              |
| 04/30/99    | 64.6             | 478              |
| 05/06/99    | 75.9             | 535              |
| 05/12/99    | 75.6             | 505              |
| 05/18/99    | 83.2             | 378              |
| 05/24/99    | 118              | 342              |
| 05/30/99    | 135              | 325              |
| 06/05/99    | 152              | 347              |
| 06/11/99    | 85.6             | 309              |
| 06/17/99    | 76.6             | 319              |
| 06/29/99    | 93.4             | 473              |
| 07/03/99    | 99.6             | 626              |
| 07/09/99    | 132              | 605              |
| 07/15/99    | 115              | 585              |
| 07/21/99    | 130              | 496              |
| 07/27/99    | 190              | 495              |
| 08/10/99    | 204              | 482              |
| 09/20/99    | 206              | 657              |
| 10/11/99    | 198              | 780              |
| 10/27/99    | 227              | 851              |
| 11/23/99    | 205              | 889              |
| 12/13/99    | 182              | 724              |
| 01/07/00    | 218              | 685              |
| 01/23/00    | 243              | 722              |

<sup>a</sup> Not Sampled



Table B-12 Chloride Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | 22.2             | NS               |
| 02/01/99    | 19.3             | NS               |
| 02/03/99    | 17.6             | NS               |
| 02/05/99    | 14.5             | NS               |
| 02/07/99    | 14.0             | NS               |
| 02/09/99    | 18.9             | NS               |
| 02/11/99    | 15.9             | NS               |
| 02/13/99    | 14.3             | 25.7             |
| 02/15/99    | 16.8             | 32.9             |
| 02/17/99    | 21.1             | 28.7             |
| 02/19/99    | 21.1             | 26.5             |
| 02/21/99    | 21.6             | 23.6             |
| 02/23/99    | 21.6             | 24.0             |
| 03/01/99    | 27.3             | 27.1             |
| 03/07/99    | 18.0             | 23.3             |
| 03/13/99    | 12.7             | 25.5             |
| 03/19/99    | 7.3              | 25.2             |
| 03/25/99    | 5.7              | 27.8             |
| 03/31/99    | 9.7              | 24.1             |
| 04/06/99    | 4.2              | 20.9             |
| 04/12/99    | 4.1              | 20.0             |
| 04/18/99    | 5.8              | 17.4             |
| 04/24/99    | 5.5              | 14.0             |
| 04/30/99    | 3.1              | 14.8             |
| 05/06/99    | 4.5              | 22.3             |
| 05/12/99    | 4.4              | 15.9             |
| 05/18/99    | 4.6              | 17.2             |
| 05/24/99    | 2.6              | 13.6             |
| 05/30/99    | 2.6              | 13.3             |
| 06/05/99    | 2.9              | 9.1              |
| 06/11/99    | 2.5              | 10.3             |
| 06/17/99    | 2.4              | 8.4              |
| 06/29/99    | 2.5              | 10.0             |
| 07/03/99    | 2.3              | 8.3              |
| 07/09/99    | 1.8              | 10.2             |
| 07/15/99    | 1.7              | 12.0             |
| 07/21/99    | 1.7              | 10.9             |
| 07/27/99    | 4.2              | 11.2             |
| 08/10/99    | 3.4              | 8.1              |
| 09/20/99    | 3.5              | 7.0              |
| 10/11/99    | 4.1              | 6.9              |
| 10/27/99    | 3.7              | 7.3              |
| 11/23/99    | 3.6              | 6.6              |
| 12/13/99    | 3.5              | 6.2              |
| 01/07/00    | 3.3              | 5.6              |
| 01/23/00    | 3.3              | 5.1              |

<sup>a</sup> Not Sampled

Table B-13 Fluoride Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

Table B-14 Nitrate Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

Table B-15 Nitrite Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

**Table B-16 Phosphate Results in Experiment 2** unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

Table B-17 Bromide Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

**Table B-18 Calcium Results in Experiment 2** unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 274              | NS <sup>a</sup>  |
| 02/01/99    | 286              | NS               |
| 02/03/99    | 278              | NS               |
| 02/05/99    | 283              | NS               |
| 02/07/99    | 273              | NS               |
| 02/09/99    | 276              | NS               |
| 02/11/99    | 317              | NS               |
| 02/13/99    | 343              | NS               |
| 02/15/99    | 372              | NS               |
| 02/17/99    | 425              | 529              |
| 02/19/99    | 456              | 552              |
| 02/23/99    | 447              | 588              |
| 02/25/99    | 427              | 580              |
| 03/01/99    | 382              | 568              |
| 03/03/99    | 393              | 577              |
| 03/07/99    | 403              | 586              |
| 03/09/99    | 397              | 596              |
| 03/13/99    | 390              | 605              |
| 03/19/99    | 373              | 582              |
| 03/25/99    | 297              | 570              |
| 03/31/99    | 332              | 551              |
| 04/06/99    | 334              | 568              |
| 04/12/99    | 323              | 549              |
| 04/18/99    | 327              | 555              |
| 04/24/99    | 265              | 553              |
| 04/30/99    | 273              | 535              |
| 05/06/99    | 305              | 554              |
| 05/12/99    | 257              | 524              |
| 05/18/99    | 272              | 501              |
| 05/24/99    | 265              | 481              |
| 05/30/99    | 299              | 503              |
| 06/05/99    | 286              | 429              |
| 06/11/99    | 222              | 441              |
| 06/17/99    | 216              | 487              |
| 06/29/99    | 244              | 486              |
| 07/03/99    | 195              | 476              |
| 07/09/99    | 203              | 523              |
| 07/15/99    | 244              | 598              |
| 07/21/99    | 240              | 542              |
| 07/27/99    | 222              | 487              |
| 08/10/99    | 195              | 469              |
| 09/20/99    | 197              | 485              |
| 10/11/99    | 197              | 550              |
| 10/27/99    | 238              | 517              |
| 11/23/99    | 214              | 577              |
| 12/13/99    | 196              | 567              |
| 01/07/00    | 212              | 541              |
| 01/23/00    | 215              | 529              |

<sup>a</sup> Not Sampled

**Table B-19 Sodium Results in Experiment 2** unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 147              | NS <sup>a</sup>  |
| 02/01/99    | 126              | NS               |
| 02/03/99    | 107              | NS               |
| 02/05/99    | 87.1             | NS               |
| 02/07/99    | 77.9             | NS               |
| 02/09/99    | 72.4             | NS               |
| 02/11/99    | 66.8             | NS               |
| 02/13/99    | 63.4             | NS               |
| 02/15/99    | 62.5             | NS               |
| 02/17/99    | 61.6             | 193              |
| 02/19/99    | 58.4             | 171              |
| 02/23/99    | 59.3             | 165              |
| 02/25/99    | 60.7             | 160              |
| 03/01/99    | 56.6             | 159              |
| 03/03/99    | 55.5             | 148              |
| 03/07/99    | 54.3             | 136              |
| 03/09/99    | 54.1             | 141              |
| 03/13/99    | 53.9             | 146              |
| 03/19/99    | 40.4             | 140              |
| 03/25/99    | 34.9             | 177              |
| 03/31/99    | 33.5             | 181              |
| 04/06/99    | 28.0             | 174              |
| 04/12/99    | 25.6             | 156              |
| 04/18/99    | 22.9             | 146              |
| 04/24/99    | 19.6             | 135              |
| 04/30/99    | 19.4             | 130              |
| 05/06/99    | 18.3             | 147              |
| 05/12/99    | 15.7             | 122              |
| 05/18/99    | 20.6             | 137              |
| 05/24/99    | 15.1             | 121              |
| 05/30/99    | 15.9             | 109              |
| 06/05/99    | 14.2             | 89.6             |
| 06/11/99    | 12.6             | 85.5             |
| 06/17/99    | 13.2             | 85.2             |
| 06/29/99    | 16.2             | 104              |
| 07/03/99    | 14.3             | 67.3             |
| 07/09/99    | 12.4             | 86.2             |
| 07/15/99    | 12.7             | 82.7             |
| 07/21/99    | 11.6             | 72.3             |
| 07/27/99    | 10.4             | 64.4             |
| 08/10/99    | 9.2              | 60.1             |
| 09/20/99    | 8.1              | 55.8             |
| 10/11/99    | 6.4              | 56.1             |
| 10/27/99    | 10.2             | 58.4             |
| 11/23/99    | 7.7              | 60.8             |
| 12/13/99    | 7.1              | 51.9             |
| 01/07/00    | 7.3              | 47.7             |
| 01/23/00    | 7.4              | 43.3             |

<sup>a</sup> Not Sampled



Table B-20 Potassium Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 26.1             | NS <sup>a</sup>  |
| 02/01/99    | 22.2             | NS               |
| 02/03/99    | 20.4             | NS               |
| 02/05/99    | 18.5             | NS               |
| 02/07/99    | 17.4             | NS               |
| 02/09/99    | 16.6             | NS               |
| 02/11/99    | 15.8             | NS               |
| 02/13/99    | 16.0             | NS               |
| 02/15/99    | 15.5             | NS               |
| 02/17/99    | 15.0             | 40.1             |
| 02/19/99    | 13.9             | 37.6             |
| 02/23/99    | 11.9             | 35.9             |
| 02/25/99    | 13.1             | 33.5             |
| 03/01/99    | 12.4             | 33.6             |
| 03/03/99    | 12.7             | 30.5             |
| 03/07/99    | 12.9             | 27.4             |
| 03/09/99    | 12.5             | 28.0             |
| 03/13/99    | 12.0             | 28.5             |
| 03/19/99    | 9.5              | 28.1             |
| 03/25/99    | 8.6              | 33.7             |
| 03/31/99    | 8.3              | 36.0             |
| 04/06/99    | 7.3              | 36.3             |
| 04/12/99    | 6.5              | 32.8             |
| 04/18/99    | 6.0              | 30.5             |
| 04/24/99    | 5.1              | 28.4             |
| 04/30/99    | 5.0              | 26.9             |
| 05/06/99    | 4.5              | 31.5             |
| 05/12/99    | 3.9              | 26.0             |
| 05/18/99    | 4.3              | 28.3             |
| 05/24/99    | 3.8              | 25.8             |
| 05/30/99    | 3.6              | 23.5             |
| 06/05/99    | 3.1              | 19.9             |
| 06/11/99    | 2.7              | 18.8             |
| 06/17/99    | 2.7              | 17.8             |
| 06/29/99    | 3.1              | 21.5             |
| 07/03/99    | 2.7              | 13.3             |
| 07/09/99    | 2.3              | 17.4             |
| 07/15/99    | 2.3              | 16.9             |
| 07/21/99    | 2.2              | 14.6             |
| 07/27/99    | 2.5              | 13.3             |
| 08/10/99    | 1.8              | 12.6             |
| 09/20/99    | 2.3              | 11.8             |
| 10/11/99    | 1.2              | 11.2             |
| 10/27/99    | 2.0              | 12.1             |
| 11/23/99    | 1.3              | 11.0             |
| 12/13/99    | 1.1              | 9.6              |
| 01/07/00    | 1.1              | 8.3              |
| 01/23/00    | 1.1              | 7.5              |

<sup>a</sup> Not Sampled

Table B-21 Magnesium Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | 14.1             | NS <sup>a</sup>  |
| 02/01/99    | 13.4             | NS               |
| 02/03/99    | 12.4             | NS               |
| 02/05/99    | 11.3             | NS               |
| 02/07/99    | 11.3             | NS               |
| 02/09/99    | 11.7             | NS               |
| 02/11/99    | 12.0             | NS               |
| 02/13/99    | 12.5             | NS               |
| 02/15/99    | 13.6             | NS               |
| 02/17/99    | 14.7             | 24.2             |
| 02/19/99    | 15.3             | 22.7             |
| 02/23/99    | 15.2             | 23.4             |
| 02/25/99    | 16.6             | 22.1             |
| 03/01/99    | 15.7             | 22.6             |
| 03/03/99    | 15.8             | 21.4             |
| 03/07/99    | 15.8             | 20.2             |
| 03/09/99    | 16.0             | 21.5             |
| 03/13/99    | 16.2             | 22.8             |
| 03/19/99    | 11.9             | 22.8             |
| 03/25/99    | 10.8             | 29.5             |
| 03/31/99    | 10.7             | 31.9             |
| 04/06/99    | 9.6              | 32.3             |
| 04/12/99    | 8.8              | 31.0             |
| 04/18/99    | 8.4              | 30.5             |
| 04/24/99    | 7.2              | 29.6             |
| 04/30/99    | 7.1              | 28.5             |
| 05/06/99    | 7.5              | 33.3             |
| 05/12/99    | 5.7              | 28.8             |
| 05/18/99    | 7.2              | 31.8             |
| 05/24/99    | 6.2              | 29.8             |
| 05/30/99    | 6.7              | 27.1             |
| 06/05/99    | 6.0              | 22.5             |
| 06/11/99    | 5.4              | 21.6             |
| 06/17/99    | 5.6              | 21.9             |
| 06/29/99    | 6.5              | 28.9             |
| 07/03/99    | 6.0              | 19.1             |
| 07/09/99    | 5.0              | 24.4             |
| 07/15/99    | 5.0              | 24.1             |
| 07/21/99    | 5.2              | 21.0             |
| 07/27/99    | 4.8              | 18.5             |
| 08/10/99    | 4.1              | 18.0             |
| 09/20/99    | 4.4              | 18.0             |
| 10/11/99    | 3.6              | 20.2             |
| 10/27/99    | 5.9              | 23.8             |
| 11/23/99    | 4.8              | 26.1             |
| 12/13/99    | 4.3              | 23.0             |
| 01/07/00    | 5.6              | 21.5             |
| 01/23/00    | 5.9              | 20.9             |

<sup>a</sup> Not Sampled

Table B-22 Ammonium Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/30/99    | BDL <sup>a</sup> | NS <sup>b</sup>  |
| 02/01/99    | BDL              | NS               |
| 02/03/99    | BDL              | NS               |
| 02/05/99    | BDL              | NS               |
| 02/07/99    | BDL              | NS               |
| 02/09/99    | BDL              | NS               |
| 02/11/99    | BDL              | NS               |
| 02/13/99    | BDL              | BDL              |
| 02/15/99    | BDL              | BDL              |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/21/99    | BDL              | BDL              |
| 02/23/99    | BDL              | BDL              |
| 02/25/99    | BDL              | BDL              |
| 02/27/99    | BDL              | BDL              |
| 03/01/99    | BDL              | BDL              |
| 03/07/99    | BDL              | BDL              |
| 03/13/99    | BDL              | BDL              |
| 03/19/99    | BDL              | BDL              |
| 03/23/99    | BDL              | BDL              |
| 03/25/99    | BDL              | BDL              |
| 03/29/99    | BDL              | BDL              |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Below Detection Limit: 1 mg/L, <sup>b</sup> Not Sampled

**Table B-23 Arsenic Results in Experiment 2** unit: µg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | 46.1             | NS               |
| 02/01/99    | 90.0             | NS               |
| 02/05/99    | 98.1             | NS               |
| 02/07/99    | 125              | NS               |
| 02/11/99    | 140              | NS               |
| 02/13/99    | 138              | NS               |
| 02/17/99    | 94.5             | 362              |
| 02/19/99    | 92.1             | 264              |
| 02/23/99    | 76.6             | 378              |
| 02/25/99    | 61.0             | 240              |
| 03/01/99    | 45.9             | 237              |
| 03/03/99    | 49.6             | 204              |
| 03/07/99    | 53.2             | 171              |
| 03/09/99    | 56.3             | 121              |
| 03/13/99    | 59.4             | 114              |
| 03/15/99    | 63.0             | 52.9             |
| 03/19/99    | 66.5             | 55.9             |
| 03/25/99    | 47.2             | 107              |
| 03/31/99    | 54.7             | 92.6             |
| 04/06/99    | 50.1             | 103              |
| 04/12/99    | 43.7             | 113              |
| 04/18/99    | 42.1             | 108              |
| 04/24/99    | 39.6             | 94.5             |
| 04/26/99    | 37.0             | 85.9             |
| 04/30/99    | 33.2             | 77.2             |
| 05/06/99    | 59.9             | 85.1             |
| 05/12/99    | 30.2             | 66.6             |
| 05/18/99    | 29.2             | 90.3             |
| 05/24/99    | 14.2             | 60.3             |
| 05/30/99    | 19.0             | 48.7             |
| 06/05/99    | 20.1             | 47.6             |
| 06/11/99    | 10.2             | 43.8             |
| 06/17/99    | 13.9             | 33.1             |
| 06/29/99    | 16.5             | 51.9             |
| 07/03/99    | 13.3             | 65.0             |
| 07/09/99    | 11.6             | 41.5             |
| 07/15/99    | 10.9             | 42.6             |
| 07/21/99    | 24.5             | 48.6             |
| 07/27/99    | 14.8             | 26.9             |
| 08/10/99    | 13.3             | 28.5             |
| 09/20/99    | 13.2             | 26.9             |
| 10/11/99    | 16.9             | 28.9             |
| 10/27/99    | 18.9             | 35.2             |
| 11/23/99    | 17.1             | 27.4             |
| 12/13/99    | 8.5              | 21.9             |
| 01/07/00    | 6.3              | 15.5             |
| 01/23/00    | BDL <sup>b</sup> | 10.9             |

<sup>a</sup> Not Sampled, <sup>b</sup> Below Detection Limit: 5 µg/L

**Table B-24 Chromium Results in Experiment 2** unit:  $\mu\text{g/L}$ 

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 02/09/99    | 54.5             | NS               |
| 02/17/99    | 140              | 145              |
| 02/19/99    | 150              | 136              |
| 02/23/99    | 155              | 126              |
| 02/25/99    | 160              | 122              |
| 03/01/99    | 182              | 118              |
| 03/07/99    | 288              | 93.7             |
| 03/13/99    | 327              | 133              |
| 03/19/99    | 277              | 124              |
| 03/31/99    | 289              | 116              |
| 04/12/99    | 188              | 140              |
| 04/18/99    | 185              | 165              |
| 04/24/99    | 181              | 142              |
| 04/30/99    | 165              | 120              |
| 05/06/99    | 157              | 152              |
| 05/18/99    | 149              | 143              |
| 05/24/99    | 110              | 133              |
| 05/30/99    | 71.8             | 127              |
| 06/11/99    | 80.4             | 121              |
| 06/17/99    | 88.9             | 126              |
| 06/29/99    | 75.0             | 131              |
| 07/09/99    | 61.1             | 136              |
| 07/27/99    | 63.8             | 142              |
| 08/10/99    | 64.5             | 135              |
| 09/20/99    | 45.9             | 120              |
| 10/11/99    | 40.1             | 142              |
| 10/27/99    | 40.0             | 126              |
| 11/23/99    | 24.2             | 97.2             |
| 12/13/99    | 27.6             | 81.7             |
| 01/07/00    | 21.9             | 78.6             |
| 01/23/00    | 13.3             | 71.9             |

<sup>a</sup> Not Sampled

Table B-25 Copper Results in Experiment 2 unit:  $\mu\text{g/L}$ 

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | 40.3             | NS               |
| 02/01/99    | 34.3             | NS               |
| 02/05/99    | 26.0             | NS               |
| 02/07/99    | 25.1             | NS               |
| 02/11/99    | 27.0             | NS               |
| 02/17/99    | 19.7             | 155              |
| 02/19/99    | 20.0             | 83.4             |
| 02/23/99    | 13.4             | 85.9             |
| 02/25/99    | 15.7             | 69.5             |
| 03/01/99    | 16.0             | 48.3             |
| 03/03/99    | BDL <sup>b</sup> | 40.6             |
| 03/07/99    | BDL              | 19.7             |
| 03/09/99    | BDL              | 20.2             |
| 03/13/99    | BDL              | 15.3             |
| 03/19/99    | BDL              | 7.1              |
| 03/25/99    | BDL              | 14.5             |
| 03/31/99    | BDL              | BDL              |
| 04/06/99    | BDL              | BDL              |
| 04/12/99    | BDL              | BDL              |
| 04/18/99    | BDL              | BDL              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Not Sampled, <sup>b</sup> Below Detection Limit: 5  $\mu\text{g/L}$

Table B-26 Iron Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | 0.32             | NS               |
| 02/01/99    | 0.59             | NS               |
| 02/05/99    | 0.81             | NS               |
| 02/07/99    | 0.98             | NS               |
| 02/11/99    | 1.92             | NS               |
| 02/13/99    | 2.78             | NS               |
| 02/17/99    | 6.88             | 0.33             |
| 02/19/99    | 7.51             | 0.38             |
| 02/23/99    | 7.01             | 0.41             |
| 02/25/99    | 6.17             | 0.45             |
| 03/01/99    | 3.34             | 0.60             |
| 03/03/99    | 2.18             | 0.78             |
| 03/07/99    | 1.02             | 1.59             |
| 03/09/99    | 0.87             | 2.14             |
| 03/13/99    | 0.71             | 2.26             |
| 03/15/99    | 0.66             | 1.40             |
| 03/19/99    | 0.60             | 1.26             |
| 03/25/99    | 0.60             | 0.86             |
| 03/31/99    | 0.44             | 0.72             |
| 04/06/99    | 0.34             | 0.53             |
| 04/12/99    | 0.30             | 0.44             |
| 04/18/99    | 0.32             | 0.47             |
| 04/24/99    | 0.45             | 0.47             |
| 04/26/99    | 0.57             | 0.44             |
| 04/30/99    | 0.30             | 0.41             |
| 05/06/99    | 0.27             | 0.49             |
| 05/12/99    | 0.32             | 0.50             |
| 05/18/99    | 0.42             | 0.75             |
| 05/24/99    | 0.35             | 0.56             |
| 05/30/99    | 0.56             | 0.41             |
| 06/05/99    | 0.39             | 0.37             |
| 06/11/99    | 0.43             | 0.29             |
| 06/17/99    | 0.83             | 0.27             |
| 06/29/99    | 0.45             | 0.40             |
| 07/03/99    | 0.58             | 0.42             |
| 07/09/99    | 0.40             | 0.29             |
| 07/15/99    | 0.26             | 0.12             |
| 07/27/99    | 0.27             | 0.12             |
| 08/10/99    | 0.35             | 0.13             |
| 09/20/99    | 0.33             | 0.12             |
| 10/11/99    | 0.42             | 0.16             |
| 10/27/99    | 0.20             | 0.10             |
| 11/23/99    | 0.32             | BDL <sup>b</sup> |
| 12/13/99    | 0.43             | BDL              |
| 01/07/00    | 0.59             | 0.1              |
| 01/23/00    | 1.36             | BDL              |

<sup>a</sup> Not Sampled <sup>b</sup> Below Detection Limit: 0.1 mg/L

Table B-27 Manganese Results in Experiment 2 unit: mg/L

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | 0.54             | NS               |
| 02/01/99    | 0.57             | NS               |
| 02/05/99    | 0.65             | NS               |
| 02/07/99    | 0.71             | NS               |
| 02/11/99    | 0.85             | NS               |
| 02/13/99    | 0.94             | NS               |
| 02/17/99    | 1.11             | 0.64             |
| 02/19/99    | 1.22             | 0.70             |
| 02/23/99    | 1.18             | 0.92             |
| 02/25/99    | 1.29             | 1.04             |
| 03/01/99    | 1.16             | 1.28             |
| 03/03/99    | 1.11             | 1.27             |
| 03/07/99    | 1.06             | 1.36             |
| 03/09/99    | 0.95             | 1.39             |
| 03/13/99    | 0.84             | 1.43             |
| 03/15/99    | 0.78             | 1.39             |
| 03/19/99    | 0.71             | 1.36             |
| 03/25/99    | 0.67             | 1.29             |
| 03/31/99    | 0.55             | 0.91             |
| 04/06/99    | 0.53             | 0.58             |
| 04/12/99    | 0.53             | 0.45             |
| 04/18/99    | 0.51             | 0.41             |
| 04/24/99    | 0.49             | 0.43             |
| 04/26/99    | 0.46             | 0.43             |
| 04/30/99    | 0.41             | 0.44             |
| 05/06/99    | 0.40             | 0.64             |
| 05/12/99    | 0.40             | 0.47             |
| 05/18/99    | 0.46             | 0.49             |
| 05/24/99    | 0.42             | 0.37             |
| 05/30/99    | 0.48             | 0.36             |
| 06/05/99    | 0.46             | 0.34             |
| 06/11/99    | 0.40             | 0.34             |
| 06/17/99    | 0.40             | 0.39             |
| 06/29/99    | 0.38             | 0.63             |
| 07/03/99    | 0.37             | 0.88             |
| 07/09/99    | 0.37             | 0.77             |
| 07/15/99    | 0.32             | 0.66             |
| 07/27/99    | 0.33             | 0.59             |
| 08/10/99    | 0.29             | 0.51             |
| 09/20/99    | 0.26             | 0.50             |
| 10/11/99    | 0.23             | 0.61             |
| 10/27/99    | 0.27             | 0.82             |
| 11/23/99    | 0.31             | 0.86             |
| 12/13/99    | 0.26             | 0.78             |
| 01/07/00    | 0.27             | 0.70             |
| 01/23/00    | 0.31             | 0.68             |

<sup>a</sup> Not Sampled



**Table B-28 Zinc Results in Experiment 2**

 unit:  $\mu\text{g/L}$ 

| Sample Date | Single Lysimeter | Serial Lysimeter |
|-------------|------------------|------------------|
| 01/23/99    | NS <sup>a</sup>  | NS               |
| 01/25/99    | NS               | NS               |
| 01/28/99    | NS               | NS               |
| 01/30/99    | BDL <sup>b</sup> | NS               |
| 02/01/99    | BDL              | NS               |
| 02/05/99    | 105              | NS               |
| 02/07/99    | 178              | NS               |
| 02/11/99    | 192              | NS               |
| 02/13/99    | BDL              | NS               |
| 02/17/99    | BDL              | BDL              |
| 02/19/99    | BDL              | BDL              |
| 02/23/99    | BDL              | 102              |
| 02/25/99    | BDL              | 141              |
| 03/01/99    | BDL              | 387              |
| 03/03/99    | BDL              | 366              |
| 03/07/99    | BDL              | 480              |
| 03/09/99    | BDL              | 293              |
| 03/13/99    | BDL              | 229              |
| 03/15/99    | BDL              | 165              |
| 03/19/99    | BDL              | 119              |
| 03/25/99    | BDL              | 409              |
| 03/31/99    | BDL              | 572              |
| 04/06/99    | BDL              | 234              |
| 04/12/99    | BDL              | 156              |
| 04/18/99    | BDL              | 104              |
| 04/24/99    | BDL              | BDL              |
| 04/26/99    | BDL              | BDL              |
| 04/30/99    | BDL              | BDL              |
| 05/06/99    | BDL              | BDL              |
| 05/12/99    | BDL              | BDL              |
| 05/18/99    | BDL              | BDL              |
| 05/24/99    | BDL              | BDL              |
| 05/30/99    | BDL              | BDL              |
| 06/05/99    | BDL              | BDL              |
| 06/11/99    | BDL              | BDL              |
| 06/17/99    | BDL              | BDL              |
| 06/29/99    | BDL              | BDL              |
| 07/03/99    | BDL              | BDL              |
| 07/09/99    | BDL              | BDL              |
| 07/15/99    | BDL              | BDL              |
| 07/21/99    | BDL              | BDL              |
| 07/27/99    | BDL              | BDL              |
| 08/10/99    | BDL              | BDL              |
| 09/20/99    | BDL              | BDL              |
| 10/11/99    | BDL              | BDL              |
| 10/27/99    | BDL              | BDL              |
| 11/23/99    | BDL              | BDL              |
| 12/13/99    | BDL              | BDL              |
| 01/07/00    | BDL              | BDL              |
| 01/23/00    | BDL              | BDL              |

<sup>a</sup> Not Sampled, <sup>b</sup> Below Detection Limit: 1 mg/L

APPENDIX C  
QUALITY CONTROL/QUALITY ASSURANCE (QA/QC)

**Table C-1 Alkalinity Duplicates in Experiment 1**

| <b>Sample</b>       | <b>Sample Concentration (mg/L as CaCO<sub>3</sub>)</b> | <b>Duplicate Concentration (mg/L as CaCO<sub>3</sub>)</b> | <b>RSD</b> |
|---------------------|--|---|------------|
| Drywall - 10/06/97  | 122  | 120   | -2%        |
| Mixed - 10/22/97    | 328  | 321   | -2%        |
| Concrete - 11/07/97 | 322  | 311   | -3%        |
| Drywall - 11/25/97  | 272  | 253   | -7%        |
| Mixed - 12/13/97    | 503  | 498   | -1%        |

**Table C-2 Total Dissolved Solids Duplicates in Experiment 1**

| <b>Sample</b>          | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|------------------------|------------------------------------|---------------------------------------|------------|
| Mixed - 10/02/97       | 710                                | 730                                   | 3%         |
| Concrete - 10/04/97    | 448                                | 402                                   | -11%       |
| Drywall Dup - 10/08/97 | 2010                               | 1980                                  | -2%        |
| Concrete - 10/12/97    | 330                                | 340                                   | 3%         |
| Drywall - 10/14/97     | 1840                               | 1820                                  | -1%        |
| Drywall Dup - 10/20/97 | 1880                               | 1840                                  | -2%        |
| Cardboard - 11/25/97   | 310                                | 380                                   | 20%        |
| Concrete - 12/19/97    | 350                                | 340                                   | -3%        |

**Table C-3 Chemical Oxygen Demand Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Standard<br/>Concentration<br/>(mg/L)</b> | <b>Calibration Check<br/>Sample<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|--|------------|
| Cal - Check 10/20/97 | 500  | 500  | 0%         |
| Cal - Check 11/25/97 | 500  | 520  | 4%         |
| Cal - Check 12/20/97 | 500  | 500  | 0%         |
| Cal - Check 12/31/97 | 500  | 520  | 4%         |

**Table C-4 Chemical Oxygen Demand Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard<br/>Concentration<br/>(mg/L)</b> | <b>Calibration Check<br/>Sample<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|--|------------|
| Cal - Check 10/20/97 | 500  | 500  | 0%         |
| Cal - Check 11/25/97 | 500  | 520  | 4%         |
| Cal - Check 12/20/97 | 500  | 500  | 0%         |
| Cal - Check 12/31/97 | 500  | 520  | 4%         |

**Table C-5 Non-Purgeable Organic Carbon Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|------------------------------------|---------------------------------------|------------|
| Mixed - 09/28/97     | 35.0                               | 33.0                                  | -6%        |
| Drywall - 10/04/97   | 60.7                               | 66.4                                  | 9%         |
| Cardboard - 10/08/97 | 59.9                               | 67.0                                  | 11%        |
| Wood - 10/16/97      | 250                                | 213                                   | -16%       |
| Cardboard - 10/26/97 | 350                                | 353                                   | 1%         |
| Wood - 10/26/97      | 206                                | 223                                   | 8%         |
| Mixed - 11/19/97     | 93.7                               | 89.5                                  | -5%        |
| Mixed - 12/13/97     | 29.4                               | 25.4                                  | -15%       |

**Table C-6 Non-Purgeable Organic Carbon Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal - Check 10/21/97 | 20.0                                 | 18.5   | -8%        |
| Cal - Check 11/04/97 | 20.0                                 | 20.1   | 0%         |
| Cal - Check 11/26/97 | 20.0                                 | 20.5   | 2%         |
| Cal - Check 12/27/97 | 20.0                                 | 18.3   | -9%        |

**Table C-7 Chloride Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|------------------------------------|---------------------------------------|------------|
| Cardboard - 10/02/97 | 7.0                                | 7.0                                   | 0%         |
| Concrete - 10/06/97  | 12.4                               | 12.4                                  | 0%         |
| Wood - 10/20/97      | 3.4                                | 3.4                                   | 0%         |
| Mixed - 11/19/97     | 5.1                                | 5.1                                   | 0%         |
| Cardboard - 12/01/97 | 5.6                                | 5.4                                   | -4%        |
| Concrete - 12/13/97  | 7.4                                | 7.4                                   | 0%         |

**Table C-8 Chloride Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal - Check 10/14/97 | 50.0                                 | 47.8   | -4%        |
| Cal - Check 10/27/97 | 20.0                                 | 17.9   | -11%       |
| Cal - Check 12/20/97 | 10.0                                 | 10.2   | 2%         |
| Cal - Check 12/23/97 | 10.0                                 | 10.2   | 2%         |

**Table C-9 Sulfate Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|------------------------------------|---------------------------------------|------------|
| Mixed - 09/26/97     | 350                                | 350                                   | 0%         |
| Cardboard - 10/02/97 | 19.9                               | 19.8                                  | -1%        |
| Mixed - 10/04/97     | 450                                | 452                                   | 0%         |
| Concrete - 10/06/97  | 14.4                               | 14.4                                  | 0%         |
| Wood - 10/20/97      | 5.5                                | 5.5                                   | 0%         |
| Concrete - 12/13/97  | 9.6                                | 8                                     | -18%       |
| Mixed - 12/19/97     | 450                                | 467                                   | 4%         |

**Table C-10 Sulfate Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal - Check 10/14/97 | 50.0                                 | 48.0   | -4%        |
| Cal - Check 10/27/97 | 20.0                                 | 18.5   | -8%        |
| Cal - Check 12/20/97 | 10.0                                 | 10.4   | 4%         |
| Cal - Check 12/23/97 | 10.0                                 | 10.2   | 2%         |

**Table C-11 Calcium Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|------------------------------------|---------------------------------------|------------|
| Wood - 09/24/97      | 16.5                               | 16.4                                  | -1%        |
| Cardboard - 09/28/97 | 6.8                                | 6.8                                   | 0%         |
| Drywall - 10/02/97   | 149                                | 150                                   | 1%         |
| Cardboard - 10/06/97 | 5.0                                | 5.0                                   | 0%         |
| Wood - 11/13/97      | 8.0                                | 8.1                                   | 1%         |
| Concrete - 11/25/97  | 94.1                               | 93.9                                  | 0%         |
| Wood - 12/07/97      | 13.3                               | 13.1                                  | -2%        |

**Table C-12 Calcium Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal - Check 10/30/97 | 20.0                                 | 20.8   | 4%         |
| Cal - Check 11/01/97 | 20.0                                 | 20.6   | 3%         |
| Cal - Check 12/05/97 | 50.0                                 | 50.1   | 0%         |
| Cal - Check 12/08/97 | 50.0                                 | 51.8   | 4%         |



**Table C-13 Magnesium Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample<br/>Concentration<br/>(mg/L)</b> | <b>Duplicate<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|---|------------|
| Wood - 09/24/97      | 6.0  | 6.1   | 2%         |
| Cardboard - 09/28/97 | 2.0  | 2.0   | 0%         |
| Cardboard - 10/06/97 | 1.6  | 1.6   | 0%         |
| Wood - 11/13/97      | 8.0  | 8.0   | 0%         |
| Wood - 12/07/97      | 5.1  | 5.0   | -2%        |

**Table C-14 Magnesium Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard<br/>Concentration<br/>(mg/L)</b> | <b>Calibration Check<br/>Sample<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|--|------------|
| Cal - Check 10/30/97 | 20.0   | 20.8   | 4%         |
| Cal - Check 11/01/97 | 20.0   | 20.5   | 2%         |
| Cal - Check 12/05/97 | 50.0   | 48.8   | -2%        |
| Cal - Check 12/08/97 | 50.0   | 50.7   | 1%         |

**Table C-15 Potassium Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|------------------------------------|---------------------------------------|------------|
| Wood - 09/24/97      | 4.6                                | 4.6                                   | 0%         |
| Cardboard - 09/28/97 | 3.8                                | 3.8                                   | 0%         |
| Cardboard - 10/06/97 | 4.6                                | 4.6                                   | 0%         |
| Wood - 11/13/97      | 19.7                               | 19.7                                  | 0%         |
| Concrete - 11/25/97  | 25.1                               | 25.0                                  | 0%         |
| Wood - 12/07/97      | 12.8                               | 12.6                                  | -2%        |

**Table C-16 Potassium Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal - Check 10/30/97 | 20.0                                 | 20.9   | 4%         |
| Cal - Check 11/01/97 | 20.0                                 | 20.5   | 2%         |
| Cal - Check 12/05/97 | 50.0                                 | 50.2   | 0%         |
| Cal - Check 12/08/97 | 50.0                                 | 51.0   | 2%         |

**Table C-17 Sodium Duplicates in Experiment 1**

| <b>Sample</b>        | <b>Sample<br/>Concentration<br/>(mg/L)</b> | <b>Duplicate<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|---|------------|
| Wood - 09/24/97      | 2.7  | 2.7   | 0%         |
| Cardboard - 09/28/97 | 41.2                                       | 41.2  | 0%         |
| Cardboard - 10/06/97 | 52.6                                       | 52.7  | 0%         |
| Wood - 11/13/97      | 2.2  | 2.2   | 0%         |
| Concrete - 11/25/97  | 12.7                                       | 12.6  | -1%        |

**Table C-18 Sodium Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard<br/>Concentration<br/>(mg/L)</b> | <b>Calibration Check<br/>Sample<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|----------------------|--|--|------------|
| Cal - Check 10/30/97 | 20.0   | 20.7   | 3%         |
| Cal - Check 11/01/97 | 20.0   | 20.5   | 2%         |
| Cal - Check 12/05/97 | 50.0   | 50.1   | 0%         |
| Cal - Check 12/08/97 | 50.0   | 51.2   | 2%         |

**Table C-19 Alkalinity Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample<br/>Concentration<br/>(mg/L as CaCO<sub>3</sub>)</b> | <b>Duplicate<br/>Concentration<br/>(mg/L as CaCO<sub>3</sub>)</b> | <b>RSD</b> |
|-------------------|--|---|------------|
| Single - 04/26/99 | 675  | 700   | 4%         |
| Single - 05/24/99 | 550  | 550   | 0%         |
| Single - 06/17/99 | 562  | 540   | -4%        |
| Single - 07/03/99 | 530  | 530   | 0%         |
| Single - 10/27/99 | 450  | 450   | 0%         |
| Single - 01/07/00 | 430  | 430   | 0%         |
| Serial - 04/06/99 | 1200   | 1200  | 0%         |
| Serial - 04/24/99 | 1260   | 1280  | 2%         |
| Serial - 05/06/99 | 1275   | 1280  | 0%         |
| Serial - 06/11/99 | 1200   | 1200  | 0%         |
| Serial - 10/27/99 | 1000   | 1010  | 1%         |
| Serial - 01/23/00 | 850  | 840   | -1%        |

**Table C-20 Total Dissolved Solids Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample<br/>Concentration<br/>(mg/L)</b> | <b>Duplicate<br/>Concentration<br/>(mg/L)</b> | <b>RSD</b> |
|-------------------|--|---|------------|
| Single - 03/31/99 | 1089                                       | 1210  | 11%        |
| Single - 04/06/99 | 1287                                       | 1309  | 2%         |
| Single - 04/18/99 | 1166                                       | 1188  | 2%         |
| Single - 04/30/99 | 737  | 858   | 15%        |
| Single - 05/18/99 | 990  | 1000  | 1%         |
| Single - 05/30/99 | 910  | 930   | 2%         |
| Single - 06/17/99 | 680  | 670   | -1%        |
| Single - 07/03/99 | 690  | 700   | 1%         |
| Single - 07/21/99 | 730  | 790   | 8%         |
| Single - 01/07/00 | 550  | 570   | 4%         |
| Single - 01/23/00 | 770  | 700   | -10%       |
| Serial - 04/02/99 | 2980                                       | 3020  | 1%         |
| Serial - 04/12/99 | 2290                                       | 2320  | 1%         |
| Serial - 04/24/99 | 2210                                       | 2180  | -1%        |
| Serial - 05/06/99 | 2800                                       | 2880  | 3%         |
| Serial - 05/12/99 | 2200                                       | 2170  | -1%        |
| Serial - 05/24/99 | 1960                                       | 1910  | -3%        |
| Serial - 05/30/99 | 2290                                       | 2320  | 1%         |
| Serial - 06/05/99 | 1640                                       | 1670  | 2%         |
| Serial - 06/10/99 | 1700                                       | 1680  | -1%        |
| Serial - 06/29/99 | 2410                                       | 2430  | 1%         |
| Serial - 07/09/99 | 2250                                       | 2210  | -2%        |
| Serial - 06/05/99 | 1640                                       | 1670  | 2%         |
| Serial - 07/27/99 | 2120                                       | 2140  | 1%         |
| Serial - 10/11/99 | 2000                                       | 2060  | 3%         |
| Serial - 01/07/00 | 1950                                       | 2030  | 4%         |

Table C-21 Sulfide Duplicates in Experiment 2

| Sample            | Sample Concentration (mg/L as S <sup>2-</sup> ) | Duplicate Concentration (mg/L as S <sup>2-</sup> ) | RSD  |
|-------------------|---|--|------|
| Single - 02/23/99 | 5.0   | 5.6  | 11%  |
| Single - 02/25/99 | 5.9   | 6.5  | 11%  |
| Single - 03/01/99 | 10.4  | 9.9  | -5%  |
| Single - 03/29/99 | 20.0  | 20.3   | 1%   |
| Single - 03/31/99 | 24.5  | 24.0   | -2%  |
| Single - 04/02/99 | 20.4  | 21.0   | 3%   |
| Single - 04/04/99 | 27.4  | 27.3   | 0%   |
| Single - 04/08/99 | 30.0  | 28.8   | -4%  |
| Single - 04/10/99 | 28.0  | 29.3   | 4%   |
| Single - 04/12/99 | 27.8  | 29.3   | 5%   |
| Single - 04/18/99 | 24.5  | 24.5   | 0%   |
| Single - 04/26/99 | 21.0  | 20.0   | -5%  |
| Single - 04/30/99 | 18.5  | 18.9   | 2%   |
| Single - 05/24/99 | 12.0  | 11.2   | -7%  |
| Single - 06/05/99 | 9.6   | 9.9  | 3%   |
| Single - 06/17/99 | 8.5   | 8.1  | -4%  |
| Single - 08/10/99 | 7.9   | 8.9  | 13%  |
| Single - 10/27/99 | 6.0   | 5.1  | -15% |
| Single - 12/13/99 | 6.0   | 6.0  | 0%   |
| Serial - 03/23/99 | 7.7   | 7.5  | -2%  |
| Serial - 03/25/99 | 9.1   | 9.0  | -1%  |
| Serial - 04/06/99 | 28.8  | 28.5   | -1%  |
| Serial - 04/24/99 | 24.8  | 24.3   | -2%  |
| Serial - 05/06/99 | 7.3   | 8.0  | 9%   |
| Serial - 05/30/99 | 32.2  | 34.2   | 6%   |
| Serial - 06/11/99 | 34.1  | 34.5   | 1%   |
| Serial - 10/11/99 | 16.6  | 17.0   | 2%   |
| Serial - 11/23/99 | 27.0  | 22.8   | -17% |
| Serial - 01/07/00 | 18.0  | 18.4   | 2%   |

**Table C-22 Chemical Oxygen Demand Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/15/99 | 1350                               | 1350                                  | 0%         |
| Single - 03/01/99 | 1300                               | 1200                                  | -8%        |
| Single - 03/19/99 | 737                                | 858                                   | 15%        |
| Single - 05/24/99 | 238                                | 238                                   | 0%         |
| Single - 06/17/99 | 84                                 | 83                                    | -1%        |
| Single - 07/27/99 | 77                                 | 75                                    | -3%        |
| Single - 10/27/99 | 64                                 | 76                                    | 17%        |
| Single - 01/23/00 | 44                                 | 50                                    | 13%        |
| Serial - 02/23/99 | 250                                | 250                                   | 0%         |
| Serial - 03/31/99 | 582                                | 595                                   | 2%         |
| Serial - 04/18/99 | 414                                | 368                                   | -12%       |
| Serial - 05/24/99 | 405                                | 381                                   | -6%        |
| Serial - 06/17/99 | 204                                | 208                                   | 2%         |
| Serial - 07/27/99 | 149                                | 145                                   | -3%        |
| Serial - 01/23/00 | 90                                 | 95                                    | 5%         |

**Table C-23 Chemical Oxygen Demand Calibration Check in Experiment 1**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/03/99 | 500                                  | 475  | -5%        |
| Cal Check - 03/03/99 | 500                                  | 475  | -5%        |
| Cal Check - 03/31/99 | 500                                  | 500  | 0%         |
| Cal Check - 04/18/99 | 500                                  | 500  | 0%         |
| Cal Check - 06/25/99 | 500                                  | 522  | 4%         |
| Cal Check - 08/04/99 | 500                                  | 506  | 1%         |
| Cal Check - 10/07/99 | 500                                  | 510  | 2%         |
| Cal Check - 01/23/00 | 500                                  | 523  | 4%         |

**Table C-24 Non-Purgeable Organic Carbon Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/05/99 | 90.1                               | 91.0                                  | 1%         |
| Single - 02/19/99 | 504                                | 505                                   | 0%         |
| Single - 06/11/99 | 46.3                               | 42.6                                  | -8%        |
| Serial - 03/31/99 | 193                                | 187                                   | -3%        |
| Serial - 05/12/99 | 76.7                               | 82.6                                  | 7%         |
| Serial - 05/24/99 | 78.4                               | 70.7                                  | -10%       |
| Serial - 08/10/99 | 48.9                               | 48.3                                  | -1%        |
| Serial - 01/23/00 | 22.0                               | 22.7                                  | 3%         |

**Table C-25 Non-Purgeable Organic Carbon Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 02/23/99 | 20.0                                 | 20.5   | 2%         |
| Cal Check - 04/21/99 | 20.0                                 | 20.9   | 4%         |
| Cal Check - 05/28/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 08/05/99 | 20.0                                 | 19.9   | -1%        |
| Cal Check - 10/2/99  | 20.0                                 | 19.4   | -3%        |
| Cal Check - 01/20/99 | 20.0                                 | 20.2   | 1%         |
| Cal Check - 01/23/00 | 20.0                                 | 20.2   | 1%         |



**Table C-26 Chloride Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/19/99 | 21.1                               | 21                                    | 0%         |
| Single - 04/26/99 | 5.5                                | 5.3                                   | -4%        |
| Single - 05/06/99 | 4.5                                | 4.7                                   | 4%         |
| Single - 05/12/99 | 4.4                                | 4.4                                   | 0%         |
| Single - 05/18/99 | 4.6                                | 4.5                                   | -2%        |
| Single - 06/17/99 | 2.4                                | 2.6                                   | 8%         |
| Single - 01/23/00 | 3.3                                | 3.3                                   | 0%         |
| Serial - 02/23/99 | 24                                 | 23.3                                  | -3%        |
| Serial - 07/03/99 | 8.3                                | 9                                     | 8%         |
| Serial - 07/27/99 | 11.2                               | 8.6                                   | -26%       |
| Serial - 10/27/99 | 7.3                                | 7.1                                   | -3%        |
| Serial - 01/23/00 | 5.1                                | 5.1                                   | 0%         |

**Table C-27 Chloride Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/13/99 | 50.0                                 | 48.8   | -2%        |
| Cal Check - 04/26/99 | 50.0                                 | 44.6   | -11%       |
| Cal Check - 05/13/99 | 50.0                                 | 47.3   | -6%        |
| Cal Check - 05/18/99 | 50.0                                 | 46.1   | -8%        |
| Cal Check - 07/05/99 | 50.0                                 | 45.1   | -10%       |
| Cal Check - 07/06/99 | 20.0                                 | 16.4   | -20%       |
| Cal Check - 12/03/99 | 10.0                                 | 10.1   | 1%         |
| Cal Check - 12/04/99 | 10.0                                 | 10.2   | 2%         |
| Cal Check - 01/24/00 | 50.0                                 | 48.8   | -2%        |

**Table C-28 Sulfate Duplicates in Experiment 2**

| Sample            | Sample Concentration (mg/L) | Duplicate Concentration (mg/L) | RSD |
|-------------------|-----------------------------|--------------------------------|-----|
| Single - 03/01/99 | 170                         | 158                            | -8% |
| Single - 03/23/99 | 33.7                        | 31.7                           | -6% |
| Single - 03/25/99 | 66.5                        | 67.6                           | 2%  |
| Single - 04/26/99 | 33.7                        | 32.9                           | -2% |
| Single - 05/06/99 | 111                         | 110                            | -1% |
| Single - 05/18/99 | 83.2                        | 83.2                           | 0%  |
| Single - 06/17/99 | 76.6                        | 76.5                           | 0%  |
| Single - 01/23/00 | 292                         | 291                            | 0%  |
| Serial - 03/13/99 | 1162                        | 1146                           | -1% |
| Serial - 04/18/99 | 455                         | 470                            | 3%  |
| Serial - 04/06/99 | 474                         | 463                            | -2% |
| Serial - 06/17/99 | 319                         | 311                            | -3% |
| Serial - 07/03/99 | 626                         | 639                            | 2%  |
| Serial - 07/27/99 | 495                         | 500                            | 1%  |
| Serial - 01/23/00 | 722                         | 755                            | 4%  |

**Table C-29 Sulfate Calibration Check in Experiment 2**

| Sample               | Standard Concentration (mg/L) | Calibration Check Sample Concentration (mg/L) | RSD  |
|----------------------|-------------------------------|---|------|
| Cal Check - 03/13/99 | 50.0                          | 49  | -2%  |
| Cal Check - 04/26/99 | 50.0                          | 42.5  | -16% |
| Cal Check - 05/13/99 | 20.0                          | 20.7  | 3%   |
| Cal Check - 05/18/99 | 50.0                          | 45.5  | -9%  |
| Cal Check - 07/05/99 | 50.0                          | 56.2  | 12%  |
| Cal Check - 07/06/99 | 20.0                          | 18.1  | -10% |
| Cal Check - 12/03/99 | 10.0                          | 10.3  | 3%   |
| Cal Check - 12/04/99 | 10.0                          | 9.8   | -2%  |
| Cal Check - 01/27/00 | 50.0                          | 50.5  | 1%   |

**Table C-30 Calcium Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/25/99 | 427                                | 426                                   | 0%         |
| Single - 04/30/99 | 273                                | 273                                   | 0%         |
| Single - 07/27/99 | 222                                | 235                                   | 6%         |
| Single - 10/27/99 | 238                                | 238                                   | 0%         |
| Single - 01/23/99 | 215                                | 214                                   | 0%         |
| Serial - 02/25/99 | 580                                | 581                                   | 0%         |
| Serial - 04/30/99 | 535                                | 537                                   | 0%         |
| Serial - 10/11/99 | 550                                | 552                                   | 0%         |
| Serial - 10/27/99 | 516                                | 517                                   | 0%         |
| Serial - 01/23/00 | 531                                | 529                                   | 0%         |

**Table C-31 Calcium Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/03/99 | 20.0                                 | 20.7   | 3%         |
| Cal Check - 07/24/99 | 20.0                                 | 20.7   | 3%         |
| Cal Check - 07/25/99 | 20.0                                 | 21.9   | 9%         |
| Cal Check - 07/29/99 | 50.0                                 | 56.2   | 12%        |
| Cal Check - 07/30/99 | 20.0                                 | 21.4   | 7%         |
| Cal Check - 08/11/99 | 20.0                                 | 26.2   | 27%        |
| Cal Check - 11/18/99 | 10.0                                 | 9.5  | -5%        |
| Cal Check - 01/23/00 | 50.0                                 | 50.7   | 1%         |
| Cal Check - 01/24/00 | 20.0                                 | 20.3   | 1%         |

**Table C-32 Magnesium Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/25/99 | 16.6                               | 16.7                                  | 1%         |
| Single - 04/30/99 | 7.1                                | 7.1                                   | 0%         |
| Single - 07/27/99 | 4.8                                | 5.2                                   | 8%         |
| Single - 10/27/99 | 6.0                                | 5.5                                   | -9%        |
| Single - 01/23/99 | 6.0                                | 6.0                                   | 0%         |
| Serial - 02/25/99 | 22.1                               | 21.9                                  | -1%        |
| Serial - 04/30/99 | 28.5                               | 28.7                                  | 1%         |
| Serial - 10/11/99 | 20.2                               | 20.3                                  | 0%         |
| Serial - 10/27/99 | 22.0                               | 22.0                                  | 0%         |
| Serial - 01/23/00 | 20.9                               | 21.0                                  | 0%         |

**Table C-33 Magnesium Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/03/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 07/24/99 | 20.0                                 | 20.5   | 2%         |
| Cal Check - 07/25/99 | 20.0                                 | 23.1   | 14%        |
| Cal Check - 07/29/99 | 50.0                                 | 49.7   | -1%        |
| Cal Check - 07/30/99 | 20.0                                 | 20.8   | 4%         |
| Cal Check - 08/11/99 | 20.0                                 | 20.2   | 1%         |
| Cal Check - 11/18/99 | 10.0                                 | 9.8  | -2%        |
| Cal Check - 01/23/00 | 50.0                                 | 50.2   | 0%         |
| Cal Check - 01/24/00 | 20.0                                 | 20.1   | 0%         |

**Table C-34 Potassium Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/25/99 | 13.1                               | 13.2                                  | 1%         |
| Single - 04/30/99 | 5.0                                | 5.0                                   | 0%         |
| Single - 07/27/99 | 2.5                                | 2.1                                   | -17%       |
| Single - 10/27/99 | 2.0                                | 2.1                                   | 5%         |
| Single - 01/23/99 | 1.1                                | 1.1                                   | 0%         |
| Serial - 02/25/99 | 33.5                               | 33.5                                  | 0%         |
| Serial - 04/30/99 | 26.9                               | 27.2                                  | 1%         |
| Serial - 10/11/99 | 11.2                               | 11.7                                  | 4%         |
| Serial - 10/27/99 | 11.0                               | 11.0                                  | 0%         |
| Serial - 01/23/00 | 7.5                                | 7.5                                   | 0%         |

**Table C-35 Potassium Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/03/99 | 20.0                                 | 20.2   | 1%         |
| Cal Check - 07/24/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 07/25/99 | 20.0                                 | 19.9   | -1%        |
| Cal Check - 07/29/99 | 50.0                                 | 49.9   | 0%         |
| Cal Check - 07/30/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 08/11/99 | 20.0                                 | 20.3   | 1%         |
| Cal Check - 11/18/99 | 10.0                                 | 9.5  | -5%        |
| Cal Check - 01/23/00 | 50.0                                 | 50.1   | 0%         |
| Cal Check - 01/24/00 | 20.0                                 | 19.7   | -2%        |

**Table C-36 Sodium Duplicates in Experiment 2**

| <b>Sample</b>     | <b>Sample Concentration (mg/L)</b> | <b>Duplicate Concentration (mg/L)</b> | <b>RSD</b> |
|-------------------|------------------------------------|---------------------------------------|------------|
| Single - 02/25/99 | 60.7                               | 60.6                                  | 0%         |
| Single - 04/30/99 | 19.4                               | 19.4                                  | 0%         |
| Single - 07/27/99 | 10.4                               | 11.8                                  | 13%        |
| Single - 10/27/99 | 10.2                               | 10.2                                  | 0%         |
| Single - 01/23/99 | 7.4                                | 7.5                                   | 1%         |
| Serial - 02/25/99 | 159                                | 159                                   | 0%         |
| Serial - 04/30/99 | 130                                | 127                                   | -2%        |
| Serial - 10/11/99 | 56.1                               | 56.8                                  | 1%         |
| Serial - 10/27/99 | 54.8                               | 54.9                                  | 0%         |
| Serial - 01/23/00 | 43.3                               | 43.2                                  | 0%         |

**Table C-37 Sodium Calibration Check in Experiment 2**

| <b>Sample</b>        | <b>Standard Concentration (mg/L)</b> | <b>Calibration Check Sample Concentration (mg/L)</b> | <b>RSD</b> |
|----------------------|--------------------------------------|--|------------|
| Cal Check - 03/03/99 | 20.0                                 | 20.2   | 1%         |
| Cal Check - 07/24/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 07/25/99 | 20.0                                 | 20.1   | 0%         |
| Cal Check - 07/29/99 | 50.0                                 | 49.4   | -1%        |
| Cal Check - 07/30/99 | 20.0                                 | 20.4   | 2%         |
| Cal Check - 08/11/99 | 20.0                                 | 20.2   | 1%         |
| Cal Check - 11/18/99 | 10.0                                 | 9.7  | -3%        |
| Cal Check - 01/23/00 | 50.0                                 | 50.0   | 0%         |
| Cal Check - 01/24/00 | 20.0                                 | 20.1   | 0%         |

**Table C-38 Arsenic Duplicates in Experiment 2**

| Sample            | Sample Concentration (µg/L) | Duplicate Concentration (µg/L) | RSD  |
|-------------------|-----------------------------|--------------------------------|------|
| Single - 03/31/99 | 55.0                        | 52.0                           | -6%  |
| Single - 06/17/99 | 14.0                        | 19.0                           | 30%  |
| Single - 07/27/99 | 15.0                        | 20.0                           | 29%  |
| Single - 12/13/99 | 8.5                         | 9.1                            | 7%   |
| Serial - 06/17/99 | 33.0                        | 25.0                           | -28% |
| Serial - 12/13/99 | 21.9                        | 22.4                           | 2%   |

**Table C-39 Arsenic Matrix Spike Recovery in Experiment 2**

Spike Added: 50 or 100 µg/L

| Sample            | Sample Concentration (µg/L) | Matrix Spike Sample (µg/L) | Matrix Spike Duplicate (µg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-------------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 05/24/99 | 14.0                        | 65.0                       | 55.0                          | 102%                  | 82%                      |
| Single - 07/21/99 | 24.5                        | 82.0                       | 81.0                          | 115%                  | 113%                     |
| Single - 01/23/00 | BDL <sup>a</sup>            | 93.2                       | 113.0                         | 93%                   | 113%                     |
| Serial - 03/17/99 | 41.0                        | 101.0                      | 83.0                          | 120%                  | 84%                      |
| Serial - 05/24/99 | 60.0                        | 112.0                      | 119.0                         | 104%                  | 118%                     |
| Serial - 01/23/00 | 10.9                        | 114.7                      | 97.8                          | 104%                  | 87%                      |
| BLANK 1           | BDL                         | 49.0                       | NA                            | 98%                   | NA                       |
| BLANK 2           | BDL                         | 92.2                       | NA                            | 92%                   | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 5 mg/L

**Table C-40 Chromium Duplicates in Experiment 2**

| Sample            | Sample Concentration (µg/L) | Duplicate Concentration (µg/L) | RSD  |
|-------------------|-----------------------------|--------------------------------|------|
| Single - 02/19/99 | 150                         | 131                            | -14% |
| Single - 03/01/99 | 182                         | 213                            | 16%  |
| Single - 07/27/99 | 63.8                        | 45.6                           | -33% |
| Serial - 03/01/99 | 118                         | 128                            | 8%   |
| Serial - 10/27/99 | 126                         | NA                             | NA   |
| Serial - 01/07/00 | 78.6                        | 81.2                           | 3%   |

**Table C-41 Chromium Matrix Spike Recovery in Experiment 2**

Spike Added: 50 or 100 µg/L

| Sample          | Sample Concentration (µg/L) | Matrix Spike Sample (µg/L) | Matrix Spike Duplicate (µg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-----------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 021999 | 150                         | 214                        | 217                           | 128%                  | 134%                     |
| Single - 043099 | 90.9                        | 181                        | 201                           | 90%                   | 110%                     |
| Single - 102799 | 40.0                        | 109                        | 114                           | 138%                  | 148%                     |
| Single - 012300 | 13.3                        | 120                        | 127                           | 107%                  | 114%                     |
| Serial - 031999 | 73.2                        | 156                        | 166                           | 82%                   | 93%                      |
| Serial - 043099 | 120                         | 175                        | 170                           | 110%                  | 100%                     |
| Serial - 012300 | 71.9                        | 161                        | 166                           | 89%                   | 94%                      |
| BLANK 1         | BDL <sup>a</sup>            | 56.2                       | NA                            | 112%                  | NA                       |
| BLANK 2         | BDL                         | 83.5                       | NA                            | 84%                   | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 10 µg/L



**Table C-42 Copper Duplicates in Experiment 2**

| Sample          | Sample Concentration (µg/L) | Duplicate Concentration (µg/L) | RSD |
|-----------------|-----------------------------|--------------------------------|-----|
| Single - 020599 | 26                          | 26                             | 0%  |
| Serial - 030199 | 48                          | 45                             | -6% |
| Serial - 032599 | 14                          | 15                             | 7%  |

**Table C-43 Copper Matrix Spike Recovery in Experiment 2**

Spike Added: 100 µg/L

| Sample          | Sample Concentration (µg/L) | Matrix Spike Sample (µg/L) | Matrix Spike Duplicate (µg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-----------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 021999 | 20                          | 116                        | 142                           | 96%                   | 122%                     |
| Single - 043099 | BDL <sup>a</sup>            | 98                         | 97                            | 98%                   | 97%                      |
| Single - 102799 | BDL                         | 108                        | 114                           | 108%                  | 114%                     |
| Single - 012300 | BDL                         | 112                        | 119                           | 112%                  | 119%                     |
| Serial - 031999 | BDL                         | 115                        | 99                            | 115%                  | 99%                      |
| Serial - 043099 | BDL                         | 88                         | 92                            | 88%                   | 92%                      |
| Serial - 012300 | BDL                         | 104                        | 97                            | 104%                  | 97%                      |
| BLANK 1         | BDL                         | 109                        | NA                            | 109%                  | NA                       |
| BLANK 2         | BDL                         | 106                        | NA                            | 106%                  | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 10 µg/L

**Table C-44 Iron Duplicates in Experiment 2**

| Sample            | Sample Concentration (mg/L) | Duplicate Concentration (mg/L) | RSD  |
|-------------------|-----------------------------|--------------------------------|------|
| Single - 02/07/99 | 1.0                         | 1.0                            | 0%   |
| Single - 02/17/99 | 6.2                         | 6.9                            | 11%  |
| Single - 04/18/99 | 0.3                         | 0.3                            | 0%   |
| Single - 06/29/99 | 0.5                         | 0.4                            | -22% |
| Single - 01/07/00 | 0.6                         | 0.6                            | 0%   |
| Serial - 03/03/99 | 0.8                         | 0.8                            | 0%   |
| Serial - 03/15/99 | 1.4                         | 1.3                            | -7%  |
| Serial - 04/18/99 | 0.5                         | 0.5                            | 0%   |
| Serial - 07/09/99 | 0.3                         | 0.3                            | 0%   |
| Serial - 01/07/00 | 0.1                         | 0.2                            | 67%  |

**Table C-45 Iron Matrix Spike Recovery in Experiment 2**

Spike Added: 5mg/L

| Sample          | Sample Concentration (mg/L) | Matrix Spike Sample (mg/L) | Matrix Spike Duplicate (mg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-----------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 022599 | 6.2                         | 10.3                       | 10.3                          | 82%                   | 82%                      |
| Single - 050699 | 0.3                         | 5.2                        | 5.2                           | 98%                   | 98%                      |
| Single - 053099 | 0.2                         | 5.6                        | 5.6                           | 108%                  | 108%                     |
| Single - 012300 | 1.4                         | 5.7                        | 5.7                           | 86%                   | 86%                      |
| Serial - 030999 | 2.1                         | 7.1                        | 7.1                           | 100%                  | 100%                     |
| Serial - 050699 | 0.5                         | 5.3                        | 5.3                           | 96%                   | 96%                      |
| Serial - 053099 | 0.4                         | 5.2                        | 5.2                           | 96%                   | 96%                      |
| Serial - 012300 | 0.0                         | 4.7                        | 4.7                           | 94%                   | 94%                      |
| BLANK 1         | BDL <sup>a</sup>            | 5.1                        | NA                            | 102%                  | NA                       |
| BLANK 2         | BDL                         | 4.5                        | NA                            | 90%                   | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 0.1 mg/L

**Table C-46 Manganese Duplicates in Experiment 2**

| Sample            | Sample Concentration (mg/L) | Duplicate Concentration (mg/L) | RSD |
|-------------------|-----------------------------|--------------------------------|-----|
| Single - 02/07/99 | 0.7                         | 0.7                            | 0%  |
| Single - 02/17/99 | 1.1                         | 1.1                            | 0%  |
| Single - 04/18/99 | 0.5                         | 0.5                            | 0%  |
| Single - 06/29/99 | 0.4                         | 0.4                            | 0%  |
| Single - 01/07/00 | 0.3                         | 0.3                            | -4% |
| Serial - 03/03/99 | 1.3                         | 1.3                            | 0%  |
| Serial - 03/15/99 | 1.4                         | 1.4                            | 0%  |
| Serial - 04/18/99 | 0.4                         | 0.4                            | 0%  |
| Serial - 07/09/99 | 0.8                         | 0.8                            | 0%  |
| Serial - 01/07/00 | 0.7                         | 0.7                            | 1%  |

**Table C-47 Manganese Matrix Spike Recovery in Experiment 2**

Spike Added: 5mg/L

| Sample          | Sample Concentration (mg/L) | Matrix Spike Sample (mg/L) | Matrix Spike Duplicate (mg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-----------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 022599 | 1.3                         | 6.3                        | 6.3                           | 100%                  | 100%                     |
| Single - 050699 | 0.4                         | 5.4                        | 5.3                           | 100%                  | 98%                      |
| Single - 012300 | 0.3                         | 5.1                        | 5                             | 96%                   | 94%                      |
| Serial - 030999 | 1.4                         | 6.1                        | 6.4                           | 94%                   | 100%                     |
| Serial - 050699 | 0.6                         | 5.5                        | 5.6                           | 98%                   | 100%                     |
| Serial - 053099 | 0.4                         | 5.3                        | 5                             | 98%                   | 92%                      |
| Serial - 012300 | 0.7                         | 5.2                        | 5.2                           | 90%                   | 90%                      |
| BLANK 1         | BDL <sup>a</sup>            | 5                          | NA                            | 100%                  | NA                       |
| BLANK 2         | BDL                         | 4.8                        | NA                            | 96%                   | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 0.1 mg/L

**Table C-48 Zinc Duplicates in Experiment 2**

| Sample            | Sample Concentration (mg/L) | Duplicate Concentration (mg/L) | RSD |
|-------------------|-----------------------------|--------------------------------|-----|
| Single - 02/07/99 | 0.2                         | 0.2                            | 0%  |
| Single - 02/17/99 | BDL <sup>a</sup>            | BDL                            | NA  |
| Single - 04/18/99 | BDL                         | BDL                            | NA  |
| Single - 06/29/99 | BDL                         | BDL                            | NA  |
| Single - 01/07/00 | BDL                         | BDL                            | NA  |
| Serial - 03/03/99 | 0.4                         | 0.4                            | 0%  |
| Serial - 03/15/99 | 0.1                         | 0.2                            | 67% |
| Serial - 04/18/99 | BDL                         | BDL                            | NA  |
| Serial - 07/09/99 | BDL                         | BDL                            | NA  |
| Serial - 01/07/00 | BDL                         | BDL                            | NA  |

<sup>a</sup> Below Detection Limit (BDL): 0.1 mg/L**Table C-49 Zinc Matrix Spike Recovery in Experiment 2**

Spike Added: 5 mg/L

| Sample          | Sample Concentration (mg/L) | Matrix Spike Sample (mg/L) | Matrix Spike Duplicate (mg/L) | Matrix Spike Recovery | Duplicate Spike Recovery |
|-----------------|-----------------------------|----------------------------|-------------------------------|-----------------------|--------------------------|
| Single - 022599 | BDL <sup>a</sup>            | 5.4                        | 5.3                           | 108%                  | 106%                     |
| Single - 050699 | BDL                         | 5.0                        | 4.9                           | 100%                  | 98%                      |
| Single - 053099 | BDL                         | 5.3                        | 4.7                           | 106%                  | 94%                      |
| Single - 012300 | BDL                         | 5.3                        | 5.1                           | 106%                  | 94%                      |
| Serial - 030999 | 0.3                         | 5.2                        | 5.3                           | 98%                   | 100%                     |
| Serial - 050699 | BDL                         | 5.2                        | 5.4                           | 104%                  | 108%                     |
| Serial - 053099 | BDL                         | 5.3                        | 4.5                           | 106%                  | 90%                      |
| Serial - 012300 | BDL                         | 5.0                        | 5.4                           | 106%                  | 90%                      |
| BLANK 1         | BDL                         | 5.0                        | NA                            | 100%                  | NA                       |
| BLANK 2         | BDL                         | 6.7                        | NA                            | 134%                  | NA                       |

<sup>a</sup> Below Detection Limit (BDL): 0.1 mg/L

**APPENDIX D**  
**ESTIMATION OF WASTE VOLUME ( $V_1$ ) IN EXPERIMENT 2**

**Table D-1 Estimation of Waste Volume ( $V_i$ ) in Experiment 2**

| <b>C&amp;D Components</b> | <b>Volume (<math>\text{cm}^3</math>)</b> | <b>Mass (g)</b> | <b>Specific Gravity (<math>\text{g}/\text{cm}^3</math>)</b> | <b>Mass in Lysimeter (g)</b> | <b>Waste Volume (<math>\text{cm}^3</math>)</b> |
|---------------------------|--|-----------------|---|------------------------------|--|
| Wood                      | 42.9                                     | 22.03           | 0.51  | 8800                         | 17126.6  |
| CCA-Wood                  | 42.9                                     | 22.17           | 0.52  | 468                          | 905.6  |
| Rebar                     | 5.7                                      | 52.77           | 9.34  | 153                          | 16.4   |
| Drywall                   | 35.0                                     | 20.69           | 0.59  | 3415                         | 5776.8   |
| Concrete                  | 4.2                                      | 8.76            | 2.09  | 8031                         | 3838.2   |
| Gal. Steel                | 1.3                                      | 13.44           | 10.75   | 167                          | 15.5   |
| Aluminum                  | 1.3                                      | 2.14            | 1.71  | 169                          | 98.9   |
| Copper Wire               | 2.8                                      | 21.4            | 7.57  | 172                          | 22.7   |
| Shingle                   | 5.0                                      | 15.4            | 3.08  | 3775                         | 1225.7   |
| Insulation                | 25.0                                     | 3.13            | 0.13  | 166                          | 1325.3   |
| Cardboard                 | 12.5                                     | 2.24            | 0.18  | 2202                         | 12286.0  |

$$\text{Total Waste Volume } (V_i) = 42637.8 \text{ cm}^3$$

$$= 11.3 \text{ gallons}$$

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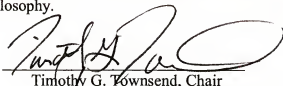
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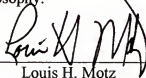
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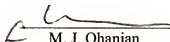


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